Economic and Social Commission for Asia and the Pacific

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Mar del Plata Action Plan

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United Nations

ESCAP and natural resources

The natural resources programme of ESCAP assists Asian and Pacific countries in strengthening their capability to meet their national objectives in three key resource areas: water, minerals and energy.

The ESCAP Natural Resources Division provides, on request, expert assistance in planning and implementing acitivities concerning assessment, development and efficient use and management of ESCAP member countries' natural resources.

The Water Resources Section of the Division promotes a comprehensive approach to development and management of national water resources, keyed to the global recommendations of the United Nations Water Conference at Mar del Plata in 1977. The Section's programme concentrates on improvement of water resources data systems, water policy and legislation, technical advisory services, efficiency in water use and dissemination of technical information through its publications. Joint activities with other organizations concern the Typhoon Operational Experiment (TOPEX) and mitigation of damage from cyclones, floods and droughts.

The Mineral Resources Section of the Division carries out programmes of review and analysis of mineral exploration and development in the region; regional geological and thematic mapping; review and compilation of the geology of the region; and studies on the mineral potential of the region. The application of new technology and the sharing of national experience are promoted through seminars and other meetings, study tours and training activities, and a network of national laboratory and training facilities which are being organized for regional use. The Section also administers programmes at subregional centres for mineral resources development, tin research and development, and joint off-shore prospecting.

The Energy Resources Section of the Division promotes the appraisal, development and management of national energy resources. The Section focuses particularly on the current "energy transition" from a mix of energy sources largely based on hydrocarbon to a new and more diversified range. The work programme includes research and information dissemination on biogas, solar power, mini-hydro power new fuels (e.g. alcohol) and a variety of "transitional" fuels (gas, methanol, coal), as well as conventional power sources. Technical assistance activities, available on request by Governments, include advisory missions, training in resource surveys and energy planning, and compilation and analysis of energy data utilizing standardized procedures.

COMMON ABBREVIATIONS USED IN THIS ISSUE

AC	alternating current	m	metre
DC	direct current	m^3	cubic metre
ft	foot	mA	milliampere
gal	gallon	mg	milligram
gpd	gallons per day	mi^2	square mile
gpm	gallons per minute	min	minute
GWh	gigawatt hour	ml	millilitre
h	hour	mm	millimetre
ha	hectare	mV	millivolt
Hz	hertz	MW	megawatt
kg	kilogram	ppm	parts per million
km	kilometre	PVC	polyvinyl chloride
km^2	square kilometre	rev	revolution
kV	kilovolt	rev/min	revolutions per minute
kVA	kilovolt-ampere	SDR	special drawing rights
kW	kilowatt	sec	second
l	litre	yr	year

ESCAP **water resources journal**

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The Economic and Social Commission for Asia and the Pacific (ESCAP) is the regional arm of the United Nations, with headquarters in Thailand. It is administratively responsible to the Secretary-General of the United Nations. At the same time it is responsible to the member countries of the ESCAP region and is subject to their parliamentary control and guidance in policy matters, under the over-all control of the Economic and Social Council.

This unique organization brings together, within Asia and the Pacific, representatives from countries throughout the world. Eastern and Western, large and small, developed and developing States sit as equals at the annual sessions of ESCAP, often called the "Parliament of Asia and the Pacific".

Water Resources Journal

Water Resources Journal is a quarterly periodical of the ESCAP Natural Resources Division. Published continuously since September 1949, the *Journal* aims to provide useful technical information on water resources for national agencies and development programmes in Asian and Pacific countries.

The contents of *Water Resources Journal* include reports on water resources programmes relevant to the ESCAP region, news of current developments and other information of regional interest, accounts of national experience applicable to other Asian and Pacific countries, and technical articles reprinted from various sources around the world. The focus is on ideas and techniques which can be applied in the context of national programmes in the region.

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MAR DEL PLATA ACTION PLAN

A PERSPECTIVE FOR ACTION:

An introduction to the global programme for the International Drinking Water Supply and Sanitation Decade 1981-1990*

The United Nations General Assembly launched the International Drinking Water Supply and Sanitation Decade on 10 November 1980, with the target of "fresh water for all by 1990".

The call for safe water supplies and sanitation by 1990 came originally from HABITAT, the United Nations Conference on Human Settlements, held at Vancouver in 1976. A year later the call was reinforced by the United Nations Water Conference, held at Mar del Plata, Argentina, which resolved that the decade of the 1980s should be dedicated to ensuring "a reliable drinking-water supply and providing basic facilities to all urban and rural communities" according to each country's own sanitary, social and economic conditions.

Participants in the Decade

The banner call of ensuring drinking water and sanitation facilities unites several international agencies in an effort to promote related causes: the United Nations itself, the United Nations Children's Fund (UNICEF) and the World Health Organization (WHO), with their joint programme on primary health care the United Nations Development Programme (UNDP) the International Labour Organisation (ILO), the Foo and Agriculture Organization of the United Nations the United Nations Educational, Scientific and Cultura Organization (UNESCO) and the World Bank. Thes organizations have formed the Steering Committee fo Co-operative Action, in order to co-ordinate work wit Governments in planning and implementing wate supply and sanitation activities. A special Global Wate Supply Unit in WHO acts as secretariat for the Committee.

The central role in the Water Decade programm is being played by communities in need of water an sanitation. Local human and material resources wil be mobilized to work toward the objectives of thi programme of safe water for all by the end of th Decade in 1990. All national Governments will b involved as well, whether they are well advanced i water and sanitation facilities or badly in need of them Governments are evolving national action plans an setting up committees to support Decade activities The industrialized countries will be providing resource for projects and activities of the Water Decade, whil developing countries are emphasizing water and sanit

The emblem of the International Drinking Water Supply and Sanitation Decade has the following components:

- The image of a drop, which is readily identified with drinking water and sanitation in all parts of the world.
- Within the large drop, signifying the Decade as a whole, ten small drops represent each year within the Decade.
- The sprinkling configuration of drops suggests the spreading of drinking water and sanitation services throughout the world, in line with the Decade goal of "clean water and adequate sanitation for all by the year 1990."
- The encircling olive-branch wreath symbolizes the United Nations' supporting and promotional role in the Decade.

1981-1990

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* The following information has been extracted from *Decade Dossier*, an introductory booklet in the UNICEF information kit on the Decade, published by UNDP in 1980.

tion in their development plans and strengthening their activities to improve their national situation.

Non-governmental organizations (NGOs) can work toward the objectives of the Decade by increasing their operational and publicity roles in the field of drinking water supply and sanitation. Business and industry can undertake public service projects by way of showing their commitment to the goals of the Decade, and supply needed equipment and services on favourable terms. The news media will be able to contribute by publicizing Water Decade activities with feature stories, films and radio and television broadcasts. Underpinning all this activity are the needed financial resources, which will be the vital contribution from funding institutions.

The combined effect

Experience shows that new water supply facilities, plus improved sanitation and excreta disposal, plus complementary programmes of hygiene education, result in a significant health impact.

Studies have revealed, for example, that:

(a) In Costa Rica, privy construction helped to halve the death rate from diarrhoea and enteritis between 1942 and 1954;

(b) Improved water supply and toilet facilities in a Philippine community cut cholera incidence by about 70 per cent;

(c) Despite the provision of clean water through tubewell installation, the incidence of cholera and diarrhoea in Bangladesh did not decrease until a personal hygiene education programme was added.

Clean water is easily contaminated and people are frequently unaware of this danger.

Integration with related services

Experience also shows that water supply and sanitation schemes have the best chance of success when integrated with other community development projects. Hunger, disease and poverty usually result from a number of prevalent conditions which complement and reinforce each other.

The relationships between safe water supply, improved sanitation, hygiene education and preventive and curative health care may be fairly clear. Links with programmes of nutrition, agriculture, family planning and so on may be less apparent, though no less vital, both for the implementation of water and sanitation programmes and for the total development of a community. For example ...

(a) Malnutrition is directly related to a lack of fresh water, since it lowers an individual's resistance to such water-borne diseases as diarrhoea. The disease reduces food intake, causing loss of body fluids and resulting in further malnutrition;

(b) A subsistence agricultural community might be reluctant to participate in water or sanitation schemes, fearing that investment in services considered non-essential could risk its chances of survival. A programme to improve agriculture might generate income for water/sanitation facilities and free labour for self-help construction work. Educational programmes could convey an awareness of the importance of water and sanitation;

(c) Water use clearly affects and is affected by, livestock grazing, crop cultivation, forest management and other economic activities. If water and related resources are not developed in proper relationship to each other, for the needed range of uses per resource, the results can include soil erosion, changed flows of creeks and rivers and diminished rainfall, making water even more difficult to obtain and ultimately leading to abandonment of villages and to urban migration.

What the Decade will cost

Estimates on what it will cost to provide everyone with clean water and adequate sanitation by the year 1990 have varied widely.

At the United Nations Water Conference in Mar del Plata, Argentina in 1977, the price tag put on the Decade was $US 140,000 million. More recently, however, the World Bank has produced figures generally considered more realistic. Costs are dramatically affected by choices of technology and scope and the level of service.

The costliest option

Based on house connexions for water supply at $120 to $150 per head, and water-borne sewage (e.g., flush toilets) at $250 per head, the first case in the illustrative box is priced in excess of $600,000 million, or $60,000 million annually (in 1978 US dollars).

It assumes that: (a) there will be 100 per cent coverage by 1990; (b) rural households will be served with standpipes or handpumps and individual latrines; and (c) urban households will receive water taps of their own and will be connected to a sewerage system.

A second option

A less expensive plan (see case 2 in box) in based on greater use of less sophisticated, lower-cost technologies, such as handpumps and pit latrines, which are perfectly capable of providing an acceptable level of service in both urban and rural areas. It also takes into account a wider mix of service levels, and an 80 per cent level of coverage by the end of the Decade. This figure, the one new cited most frequently, is $US 300,000 million, or $US 30,000 million annually.

On what basis are these total costs determined?

NEEDS:

1990 population of developing countries needing water supply and sanitation (in millions).

	Water	Sanitation
Urban	640	650
Rural	1 570	1 670
Total	2 210	2 320

COSTS:

***Per capita* costs of alternative types of water supply and sanitation (1978 $US)**

	Urban	Rural
Water supply		
with house connection	$120	$150
with standpipe	40	40
with handpumps	—	25
Sanitation		
with sewerage	250	250
with septic tank	100	—
with latrine	30	20

SOURCE: World Bank, *Basic Needs: Water Supply and Waste Disposal*, Dec. 10, 1979, pp. 6-7.

SERVICE LEVELS:

Case 1* (100% coverage using 1980 WHO Target Urban Service Standard Distribution)

Urban	Water supply	70% house connection 30% standpipe
	Sanitation	40% sewerage 40% septic tanks 20% latrine and communal latrines
Rural	Water supply	20% house connection 40% standpipe 40% handpumps
	Sanitation	80% sewerage 20% latrine

Case 2* (80% coverage with service standard as suggested)

Urban	Water supply	40% house connection 40% standpipe
	Sanitation	25% sewerage 15% septic tanks 40% latrine and communal latrines
Rural	Water supply	10% house connection 30% standpipe 40% handpumps
	Sanitation	10% sewerage 70% latrines

* Both sets of figures are only rough approximations. They are bound to rise further when costs of operation and maintenance are added to installation costs.

Funding sources

While the developing countries themselves bear major responsibility for financing new water supply and sanitation projects, estimates are that at least one fifth and perhaps one third of the funds required might have to come from external sources.

WHO estimates that in 1979 the total investment in water and sanitation in the developing world came to $US 6-7000 million, of which $US 2400 million (around 35-40 per cent) was derived from bilateral, multilateral and non-governmental aid.

To reach the target of the Decade, therefore, spending will have to more than quadruple.

There is no question that finding the necessary resources will be difficult. However, large cost savings can be made by appropriate selection of service standards, careful staging of investment and building drinking-water components into wider water-resource projects. Savings can also result from the use of self-help labour and user-financing of facilities. Revolving funds which provide loans for capital costs which community members later reimburse to finance other projects might be one solution.

Though the goals of the Water Decade are ideals toward which all will strive, each country will want to set targets it can realistically expect to meet, given its individual resources.

GOALS FOR THE DECADE

Recommendations of the United Nations Water Conference, Mar del Plata, 1977

Resolution II, on "Community water supply and waste disposal", of the 1977 United Nations Water Conference set the main perspective for action to provide water and sanitation for all during the ensuing decade. (See accompanying article for a brief description of the programme for the International Drinking Water Supply and Sanitation Decade.)

The Conference participants gathered at Mar del Plata, Argentina to plan a comprehensive global programme for managing the earth's water resources for the gamut of humanity's uses in the diverse habitats. Under Resolution II, the participants recommended that action be taken in the following ways, in order to provide water for drinking and sanitation purposes for the world's communities by 1990.

For the planning and development stage

(a) Set targets for community water supply and waste disposal and formulate specific action programmes to attain them, while evaluating the progress made at regular intervals;

(b) Establish standards of quality and quantity that are consistent with the public health, economic and social policies of Governments, ensuring by appropriate measures, duly applied, that those standards are observed;

(c) Ensure the co-ordination of community water-supply and waste-disposal planning with overall water planning and policy as well as with overall economic development;

(d) Adopt policies for the mobilization of users and local labour in the planning, financing, construction, operation and maintenance of projects for the supply of drinking water and the disposal of waste water;

(e) Consider carefully inequalities in the standard of drinking water and sewerage services among the various sectors of the population. As far as possible, design programmes so as to provide basic requirements for all communities as quickly as possible, generally deferring the provision of improved services to a subsequent stage. Priority should be given to the provision of drinking water and sewerage services in areas where the quality and quantity of water supplied are inadequate, as for instance in rural areas and urban fringe areas populated by low-income groups;

(i) Review the organizational infrastructure for community water supply and sanitation, and where this is considered appropriate, set up a separate department for this purpose;

(j) Prepare long-term plans and specific projects with detailed financial implications.

For the operational stage

(h) Provide, where needed, additional well-drilling capability or other equipment for the establishment of local drinking-water supply facilities;

(n) Adopt pricing policies and other incentives to promote the efficient use of water and the reduction of waste water, while taking due account of social objectives;

(o) Seek to promote individual water-supply and waste-water disposal systems in rural areas with low population density where appropriate, taking account of sanitary requirements;

(p) Carry out a programme of health education parallel with the development of community water supply and sanitation, in order to heighten the people's awareness with respect to health;

(q) Establish, at the national level, training programmes to meet immediate and future needs for supervisory staff;

(r) Provide an inventory and protection of water-supply sources;

(s) Provide additional facilities and possibilities for drinking water supply during natural hazards;

(t) Use water effectively, reduce losses, equalize water prices by purposes for which the water is used over wide areas, and reduce water costs due to reorganization models of some countries' water-supply arrangements so as to strengthen the financial management basis of supplies in metropolitan, urban and rural areas. Develop new concepts, such as the use of advanced water-treatment techniques, the utilization of low-quality sources and the re-use of waste water. These trends (reorganization and the use of new concepts) need to be encouraged were they are found to be necessary and desirable. Rural water-supply projects and programmes for implementing them on a priority basis are being undertaken in some countries and should be encouraged in others to achieve the targets in the field of community water supplies set by Habitat: United Nations Conference on Human Settlements.

For funding and resource mobilization

(f) Ensure that the allocation of funds, of other resources and of all forms of economic incentives to community water-supply and sanitation programmes reflects the urgency of the needs and the proportion of the population affected;

(g) Promote the construction of facilities by granting low-interest loans or subsidies to communities and to other entities concerned with water supply and sanitation;

(k) Develop a financing system capable of mobilizing the resources needs for the implementation of the national programme for water-supply and sanitation, as well as for the operation and maintenance of these services, for instance by a system of revolving funds to ensure continued financial support for the execution of long-term programmes. This system should make it possible to bridge the gap between production costs and payment capacities;

(l) Provide mutual assistance in the transfer and application of technologies associated with these programmes;

(m) Carry out special water-supply and waste-treatment programmes as national or regional undertakings or as activities of non-profit organizations, such as users' associations, where local resources do not make it possible to achieve the desired goals.

The role of ESCAP in the 1981-1990 Water Decade

The provision of adequate drinking water supplies and sanitation must be considered together with the over-all development and management of water resources, as well as with other economic and social factors of development. The role of ESCAP in the Water Decade is to organize studies, investigations and collective discussions which could help member countries to gain a fuller understanding of the technical aspects of each problem and of the alternatives available to them in terms of solutions.

The ESCAP work programme focuses mainly on common regional or subregional problems affecting groups of countries. The advantage of the ESCAP approach is its interdisciplinary character, which enables ESCAP to take a broad perspective on such problems in order to promote co-ordination in planning and implementing action programmes for solving country-specific problems. ESCAP co-operates with specialized agencies whenever necessary and possible.

Water resources

The ESCAP water resources programme includes a component on the appraisal of availability and use of water, for assisting the countries of the region in the systematic evaluation and use of their water resources, including the development of related data and information systems. The activities comprising this subprogramme involve the co-operation of FAO, UNESCO, WHO and the World Meteorological Organization (WMO).

Another component promotes the integrated development, use and management of water as a means of assisting countries in formulating appropriate national water policies, selecting appropriate institutional and legal arrangements as a framework for implementing national water policies and ensuring an integrated approach to planning and programming water development and uses for various purposes.

The various activities under the above two components of the ESCAP water resources programme have important implications for the Water Decade programme. These include a seminar on ground-water development and management; an expert group meeting on water pricing; and intergovernmental co-operation on the Mar del Plata Action Plan, including the International Drinking Water Supply and Sanitation Decade.

Activities planned for subsequent years under the same programme will include water demand projects; measures to reduce the cost of urban and rural water supply and waste disposal facilities; and a study on low-cost water and waste-water treatment processes and equipment. Most of these activities are expected to be carried out in co-operation with the appropriate specialized agencies.

Population

Appropriate population policies and programmes are important components of water demand management. ESCAP can play an important role in this regard through its Asian and Pacific population programme, which is aimed at promoting and assisting countries in the formulation and implementation of effective population policies and programmes as integral parts of the development process. It is also designed to assist them in developing, implementing and evaluating their family planning programmes in order to realize fertility goals.

Rural development

The ESCAP integrated programme on rural development aims at assisting countries in alleviating rural poverty, improving the well-being and employment opportunities of the people, particularly the low-income groups in rural areas, and integrating the rural masses in the development process through greater access to resources and improved skills and participation in decision-making. The impact of this programme should reinforce progress toward the goals of the Water Decade programme.

In the context of Water Decade activities, this integrated programme on rural development has a component on resource mobilization, use and management. The main objective is the mobilization and channeling of resources into more productive use, through institutional development of rural works and management, utilization of water resources for rural development etc.

Social development

The ESCAP programme for social development and welfare could contribute to the Water Decade by including a component on domestic hygiene in its activity on community development education and by carrying out a study on methods of increasing the acceptability of sanitation facilities in backward areas.

Human settlements

The ESCAP programme on human settlements includes such activities as improvement of slums and squatter settlements; improvement of the servicing capacity of existing human settlements systems; and physical planning of rural centres. These activities have implications for the provision of drinking water supply and sanitation services, which should be considered in planning activities related to the Water Decade programme.

Environment

Among the aims of the environmental programme of ESCAP is assistance to countries in the assessment of environmental impacts of development projects, through the development and/or strengthening of institutions and laws for environmental protection and management and through development of guidelines to minimize environmental deterioration. Related aims of the Water Decade could also be included in the ESCAP environmental programme, e.g. assessing the environmental impacts arising from the provision of drinking water supply and sanitation facilities and developing guidelines to prevent or minimize any potential negative impacts on the environment.

International organizations

With the co-operation of ILO and WHO, ESCAP could formulate guidelines on which countries could base a survey of their available manpower and needs related to the Water Decade programme.

Interagency Task Force on Water

Finally, ESCAP, which is responsible for convening the meetings of the Interagency Task Force on Water for Asia and the Pacific, has an excellent opportunity to discuss with the specialized agencies the progress and problems of the Water Decade programme, as well as to collaborate in any joint endeavours which the Task Force may propose and formulate to assist in the achievement of the Water Decade goals.

State of the World Environment

On World Environment Day, 5 June 1981, the Executive Director of the United Nations Environment Programme Dr Mostafa Tolba focused on two themes in his annual report on the state of the world environment:

- the threat of toxic chemicals to the human food chain
- hazards to the world's ground-water supplies

The importance of these two threats to environmental well-being were explained in the context of the over-all need for the world – governments, industry and the general public – to decide what price we are willing to pay for protecting the world environment. Dr Tolba affirms that full prevention is worth the price, in comparison with the costs of cleaning up after disasters.

The following comments about water resources are reproduced from the feature article "State of the world environment" published by UNDP in *Development Forum* (June 1981). (See related graphics inside the back cover which portray the deterioration of the earth's water resources under the abuses of pollution.)

Life blood of the earth

For ground water, a unique source of reliably pure, fresh water, it is too often a case of "out of sight, out of mind". "This is not simply an instance where prevention is better than cure, but where prevention is the only available option", Dr Tolba writes. "By the time subsurface pollution is conclusively identified, it is often too late to apply remedial measures that would be of much benefit. Once contaminated or depleted, ground water resources may be permanently diminished."

Noting that ground water accounts for nearly all the fresh and liquid water on land, Dr Tolba calls for stringent scrutiny of waste disposal, new procedures governing use of chemicals on land, and effective controls against pollution and over-use of ground water supplies.

Protection pays

Developing countries spend their environmental protection budgets mainly on improving drinking water supplies and sanitation. But to control pollution effectively as well, the Third World would need to allocate only between 0.5 and 1 per cent to this aim.

"Good management of the environment should be based upon avoiding wastage of resources and pollution. This is more appropriate and certainly more efficient than redressing environmental degradation after it occurs."

DEVELOPMENT POLICY AND PROGRAMMES

BREAKING THE COST BARRIER TO HOUSEHOLD WATER SERVICE

*Emmett F. Lowry**

Providing economically feasible household-connected water systems to the rural, low income areas of a developing nation is a task of almost overwhelming magnitude. The Barangay Water Program in the Philippines, however, is on the way to accomplishing just that. A check of early system installation practices uncovered some surprising facts and ultimately led to several economically viable alternatives to conventional system design.

Potable water is a universal necessity for all people, but its availability is not a universal reality. The critical problem of safe water for the rural areas of developing nations has been recognized by the United Nations General Assembly with the proclamation of the period 1981 to 1990 as the International Drinking Water Supply and Sanitation Decade. Simply bringing a cleaner supply to rural community does not necessarily imply increased water consumption and better hygiene. The water still must be carried from the source of supply to the home: there is no reduction in the time required to draw and carry the water, the only change is in the quality of the water. The crux of increasing water consumption among rural populations seems to be household-connected supplies. But for developing nations whose rural populations have very low incomes, across-the-board household supply connections may not be economically feasible.

Recognizing the needs of its rural citizens, but also aware of the fiscal constraints on household connections, the Republic of the Philippines initiated a programme to provide water service to individual *barangay* (the smallest community unit in the Philippines). The ultimate goal of the Barangay Water Programme (BWP) is to develop replicable methods that will enable potable water service to be improved throughout the rural areas of the nation. The programme created to achieve this goal was funded by a loan from the United States Agency for International Development.

One of the key aspects of the programme is to reduce the *per capita* construction cost as much as possible. Although this discussion is focused on the cost aspect, it should not be misconstrued that this is the dominant factor of the programme. The institution-building aspect is of greater import. This is emphasized because far too often the institutional aspect receives only lip service and then even beautifully conceived and implemented projects quickly deteriorate.

LEVELS OF WATER SERVICE

There are 42,000 rural *barangay* in the Philippines, in which 20 million Filipinos reside. Almost all of these communities need improved potable water service.

Some *barangay* are so small and sparsely populated that a piped water system is not justified. In these cases the traditional small well and handpump are provided. This configuration is referred to as level 1 service. The main thrust of the BWP, however, is the provision of piped water systems.

Level 2 service is defined as a piped system with strategically placed public faucets. At the beginning of the BWP three years ago, the average cost for constructing level 2 systems was $US 57 per person.

Level 3 service is the conventional household-connected system, complete with meters. Until recently, BWP constructed only level 2 piped systems. This is because the total cost of nation-wide installation of level 3 systems is too high to be justified by the relatively low rural incomes. Another factor working against the nation-wide installation of level 3 service is the unlikelihood that household meters would be maintained in good working order in remote areas.

It was also deemed unmanageable to attempt to supervise the design and construction of so many projects in far-flung places through a centrally based group of engineers. Since each province maintains its own engineering staff, BWP enlisted their assistance in performing these functions.

*** Consulting engineer, San Diego, California and technical adviser to the Barangay Water Program. This article is reprinted with permission from *Journal A WWA* (ISSN 0003-150 X), vol.72, No. 12 (December 1980), pp. 672-677. Copyright, American Water Works Association, 1980.**

PROBLEM OF PROVIDING POTABLE WATER

There are two basic facets to the problem. First, the cost for constructing piped water systems was still too high, even for level 2 systems. The price tag to build water systems nation-wide would amount to somewhere between $US 600 and $US 900 million. Second, while level 2 systems definitely improve the local situations by making safe water readily available, they still necessitate the use of water carriers. This has two serious disadvantages. The time and energy devoted to carrying water could be better used to raise food or improve the economic position of the family. But even more important, water hauling tends to restrict the amount of water used to an unhealthily low level. Hand-carried water would normally total from 1500 to 3000 litres per month for a family of six. This small volume cannot provide for basic sanitation needs.

Each of the two stated aspects of the problem was attacked individually. First, every effort was made to achieve maximum economy in the design and construction of level 2 systems. Second, a search was launched for non-conventional designs of house-connected systems that would not require expensive meters.

COST REDUCTION

Close examination revealed that the systems constructed early in the programme were substantially over-designed. Pumps were large enough to pump the maximum daily demand in four hours. This was four times as expensive as needed. Also, the oversized pumps required oversized wells. Storage tanks were large enough to provide more than 50 per cent of the daily demand, i.e. double the normal operational requirement. Storage elevations were higher than necessary to maintain minimum system pressure. Pipe sizes were larger than required by prevailing hydraulic conditions.

Formulated system design

Engineers in developed or industrialized countries are constantly in contact with colleagues who have had substantial experience in water system design and construction. It must be appreciated that this is rare in the developing world.

Recent water system design, construction, and maintenance in developing countries have been so sporadic that real experience is a scarce commodity. The result is often gross over-design, with its attendant wastage of precious funds. Civil engineers in the Philippines are no exception. They are well educated but generally lacking in practical experience. To help solve this problem, a formulated approach to system design has been developed. It leads the designer step by step through each community problem. A two-day training programme is required to familiarize engineers in groups of 25 with the methodology. Thereafter, a design can be worked up for an average community with one day of field work and four hours of office application. No formal drawings are required; sketches are adequate.

The methodology does not extend to source determination other than the comparison of alternatives. Location of ground water is still a subject that is not readily reduced to a cookbook solution. Fortunately, there are few areas in the Philippines where the ground water situation is not relatively well known.

Standardized system design criteria

The Barangay Water Programme under the Ministry of Local Government and Community Development has compressed this methodology into a technical manual. It sets forth the design criteria that will be used, determines the size and location of storage, selects pipeline sizes, presents materials specifications and arranges a bill of materials, complete with cost estimates, ready for procurement. As a result, sound, economical designs are now being created throughout the Philippines by engineers who have had no previous experience. The results have been dramatic. Before the implementation of this methodology, each provincial engineer's office performed design as it considered appropriate.

The standardization of design criteria alone has been responsible for much of the cost reduction that has been achieved. A sensitivity study was made on several model communities in an effort to determine the over-all cost effect of various system pressures. It was determined that a low-pressure system was definitely more economical than a high-pressure system in flat terrain. The higher pressure system was achieved by the use of higher (and thus more expensive) elevated storage tanks. This additional expenses plus the added energy cost was substantially greater than the savings that would be realized by the use of smaller pipelines that the steeper hydraulic gradient allowed.

Standardization of storage facilities

A third significant factor in cost reduction was the standardization of storage in a standpipe configuration instead of the conventional elevated storage tank. Most of the storage requirements called for a low water level of 6 m (20 ft) above ground level and a higher water level of 9 m (30 ft). Under such conditions the lower standpipe shell is cheaper than a structural steel support. Further, no foundations are required for the standpipes. They stand freely on a flat gravel bed. In areas where good sandy soil is readily available, low-cost local labour can erect a 3-m (10-ft) high earth mound on which the standpipe can be placed. In these cases, the standpipe is shortened by the 3 m height of the mound. The end result is that storage is achieved for approximately 50 per cent of the cost of the conventional elevated configuration. As an additional bonus, the standpipe makes the normally unused water stored below the lower operational level available for such emergency uses as fire fighting or the frequent power failures.

Cost-effective materials selections

The last but very significant factor in cost reduction is the choice of materials. It had been the practice in the Philippines to use schedule 20 galvanized iron water pipe. Aside from the fact that this is not cheap, its life expectancy is on the order of 10 years.

Specifications were written that require the use of modern, high-quality plastic pipes. The smaller sizes are either polyethylene or polybutylene and the larger sizes are polyvinyl chloride (PVC). The use of plastic pipe has reduced the cost of piping materials by more than 40 per cent. Installation and assembly of the plastic pipe is being done by unskilled local labour with good results.

As a result of these efforts, level 2 water systems are now being built for an average of $US 33 per person. Compared with the early systems built three years ago at an average cost of $US 57 per person, this is a reduction of more than 50 per cent when inflation is factored in.

HOUSEHOLD DELIVERY

As previously stated, the real potential benefits of safe water cannot be realized unless water is available in the home in sufficient quantity. In a conventional system, household delivery increases the cost substantially over a public standpost system. This runs counter to the basic goal of reducing cost.

A physical combination was developed that achieves household delivery while actually reducing the system cost over the public standpost systems. The key was found to be in the term "utilization."

In conventional systems, it is common practice to design the source and transmission facilities to meet maximum day demands, while the distribution system is designed to meet peak load conditions. The operational storage facility is usually the place of transition from maximum-day to peak-hour flow rates. Since peak conditions only occur for a brief period each day, the distribution system is not being fully utilized at other times.

Relocating the maximum-day to peak-hour transition point closer to the user permits a much higher degree of utilization of the distribution system. To accomplish this, two physical changes were required. First, the operational storage had to be relocated and placed in each individual household. Second, a physical restriction had to be placed at each service lateral to preclude peaking from the main lines.

Households in the rural Philippines average six persons. BWP attempts to build systems that provide 57 l per day (15 gpd) *per capita*. This translates into 340 l per day (90 gpd) at each household connection. A theoretical continuous flow rate that provides this amount is 0.0040 l/sec (0.0625 gpm). To allow for a minimal amount of peaking, the desired flow rate was increased to 0.0064 l/sec (0.1 gpm).

Because no hard data were available on precise household consumption patterns, estimates were made for these patterns. It turned out that the storage factors required to meet these demands were almost identical with the storage factor of 25 per cent that had been developed previously for communities.

CREATING A NEW LEVEL OF SERVICE

The net result is a distribution system that is extremely small and inexpensive. Also, the amount of system storage required is insignificant. The usual elevated tank is replaced by a simple pipe that provides a water column for pressure regulation.

For identification purposes, BWP refers to this type of system as level 3A. For a typical *barangay*, level 3A service represents a savings on the order of 40 per cent over level 2 service.

Physical considerations

Level 3A service requires several physical features that are not commonly found in water systems. Each household is provided, as part of the system, with a 95 l (25 gal) storage tank equipped with a float-controlled inlet and a faucet outlet. The minimum pressures designed into all BWP systems will permit the storage container to be placed 2.4 m (8 ft) above ground. This will allow members of the household to shower and thus conserve water, as opposed to limiting them to bathing directly out of containers.

Each main connection is equipped with a restrictor that is designed to pass approximately 0.0064 l/sec (0.1 gpm). The restrictors are deliberately placed underground to discourage any attempt to tamper with them. While BWP water systems are normally under relatively low pressure, the differences are still enough to significantly affect the flow rate through fixed restrictors. To compensate for this, all systems are divided into high, intermediate, and low pressure zones and restrictors are a used that correspond to the respective zones.

POTENTIAL CONSUMPTION PATTERNS

The standard unit of measure for water in the *barangay* is the kero can (a 5 gal kerosene can). This is the way water is normally transported by carriers. As stated earlier, it is rare that more than two cans at any one time would be in a house using level 2 service.

Level 3A service, however, starts the day with the equivalent of five cans in storage. Since these systems are under continuous pressure, with the first usage of water in the home, the float value opens and water comes into the home at the rate of 23 l (6 gal) per hour.

In the tropics and the Philippines in particular, personal cleanliness is given very high priority. Several showers a day are desirable. Household laundry is done each day regardless of how small the amount.

The combination of 95 l (25 gal) storage, full in the morning, and a 23 l (6 gal) per hour replenishment rate will allow a consumption pattern on the order of the following:

Time of day	*Activity*	*Consumption (l)*
5.00 a.m.	Showers	38
6.00 a.m.	Cooking and clean-up	38
7.00 a.m.	Laundry	38
8.00 a.m. through mid-morning	Miscellaneous–gardening, cleaning piggery	56
Noon	Cooking and clean-up	38
Mid-afternoon	Miscellaneous	38
5.00 p.m.	Showers	38
6.00 p.m.	Cooking and clean-up	38
8.00 p.m.	Showers	56
9.00 p.m.	Miscellaneous	38
	Daily usage total	450

AREAS OF CONCERN

To realize the maximum potential of such a system will require a certain amount of household discipline. This is not a simple thing with an easy-going people such as the Filipinos. But more importantly, the concept itself is completely alien to the rural population. By definition, anything alien is suspect. It is felt that after several successful examples, level 3A will become accepted as a normal matter of course. It had already been established that once the concept is understood, it is warmly received by the rural population. The difficult part is bringing about that understanding. A substantial initial investment in time must be made to gradually introduce the concept to villagers. If this is not done, resistance may be great even though the advantages are real.

Another area of concern is the tendency for an occasional individual in the *barangay* to alter the system for personal advantage. This could result in tampering with a restrictor to obtain a higher flow rate. In this instance the system is very vulnerable. A removed restrictor can allow delivery of as much as 0.18 l/sec (3 gpm). This is the equivalent of 30 normal connections. The abnormal load concentrated at one point will adversely affect all surrounding consumers. The countermeasure to this is education among the controlling personalities in the *barangay* as to the seriousness of the problem, ultimately bringing peer pressure to bear on any potential offender.

CURRENT STATUS OF LEVEL 3A

As of May 1980, level 3A systems were under construction in eight diverse locations around the Philippines. The first system was scheduled to go into operation in June of 1980. There is substantial pressure to construct many more level 3A systems in places where level 2 systems are programmed. This pressure is being resisted by BWP until the pilot systems are operational, so that sufficient time is allowed to ensure that cultural and physical obstacles are all identified and satisfactorily dealt with.

FUTURE DIRECTION

The BWP is cautiously optimistic concerning level 3A. In the event that cultural resistance proves to be either light or non-existent, the likelihood is that level 3A will completely replace all level 2 service. Given the potential cost difference of up to 30 per cent between the two levels, the construction of level 2 systems would be an unwarranted squandering of funds.

As regards costs, the systems now being built incorporate such a degree of conservatism in design that further savings are possible. It is not unrealistic to expect an additional 10 per cent reduction in costs. Development work is under way on lower-pressure pipe systems, mass-produced household storate units and simpler system pressure regulation and construction methods.

The end result of these efforts is expected to be piped water systems in the rural areas delivering 450 l (120 gal) of water daily in the home for less than $US21 *per capita* construction cost.

INTEGRATED PLANNING OF RURAL WATER SUPPLY AND SANITATION

Edmundo S. Degoma, Chongrak Polprasert, and B. N. Lohani[*]

The World Health Organization in 1970 reported that only 15 per cent of the world's rural population has reasonable access to safe water and estimated that based on 1970 price levels, $US 3 billion would be required to provide safe water for 70 per cent of that population. Similarly, the "Habitat Forum" puts the required investment for providing pathogen-free water to villagers at $US 30 billion annually for a period of 14 years, beginning in 1976. Justification of this huge expenditure is primarily based on the importance of clean and safe water in improving the health and well-being of the human race, particularly in the prevention of water-borne diseases.

The scheme of concentrating resources solely on safe water provision is, however, doubtful insofar as disease prevention is concerned. Studies conducted by Azurin and Alvero in the Philippines revealed that provision of sanitary facilities alone reduced the incidence of cholera by as much as 68 per cent while the provision of safe water effected a reduction by 73 per cent. Where safe water and toilets were provided, a 76 per cent reduction was observed. Also, based on their studies on cholera/clean water relationship in Bangladesh, Levine and others reported that better water quality did not significantly reduce morbidity and mortality rates attributed to cholera. They, however, positively correlated education of inhabitants and quantity of water available to them to a reduction in cholera and dysentery levels. Saunders and Warford's findings dovetailed with Levine's. They reported that the highest incidence of diarrheal cases was found in households away from the water source, those which consumed a lesser quantity of water. Furthermore, studies conducted in Thailand indicated that the distribution of bacterial density is normally negligible after treatment and chlorination, but usually increases during transportation and storage due to recontamination to a level sometimes even higher than that of the pretreated water. In European as well as in Oriental countries, several cases have been reported in which the establishment of a water supply system in rural areas failed to check the spread of communicable waterborne and foodborne diseases.

McGarry has observed that the importance of a clean water supply in rural areas should be considered together with other equally important factors; and that these must be viewed as some kind of "sanitation package," each component of which cannot be implemented separately without losing the total health benefit it intends to generate.

A. RURAL SANITATION SYSTEM

Rural sanitation depends on a wide range of variables, as shown in figure 1. It is apparent that the rural water supply is just one of the factors responsible for the improvement of health standards of the community when the level of bacteria is taken as the criterion. It may also be noted that the contamination mostly comes from a poorly designed excreta and waste disposal subsystem which includes the spent water from bathing and washing, and animal, human and industrial wastes. The transport of these contaminants could be attributed primarily to the poor sanitary habits of the villagers.

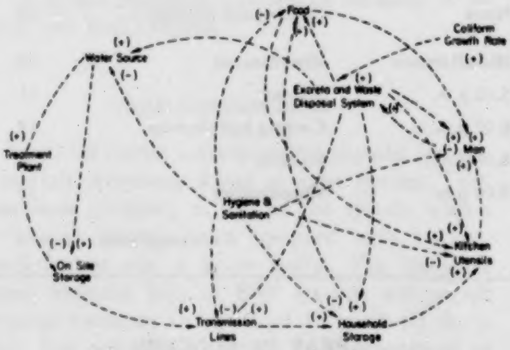

Figure 1. **Causal-loop diagram of rural water supply and sanitation**

1. *Water supply subsystem*

The water supply subsystem is broken down into five components; the raw water source, the treatment plant, on-side storage, transmission and household storage.

The water quality of the water source is influenced by contaminating factors such as industrial and domestic wastes. Supply from a well-protected water source might be consumed without the necessity of treatment. For a contaminated source, contaminants could come from upstream pollution, animal excrements, spent water from washing and bathing, and human excreta and waste disposal subsystems. All these lower the water quality and encourage the growth of algae which cause undesirable taste and bacteria, the disease-causing agents.

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[*] Respectively, graduate student, Assistant Professor, and Associate Professor, Environmental Engineering Division, Asian Institute of Technology, Bangkok, Thailand. Paper No. 78166, reprinted with permission from *Water Resources Bulletin* (ISSN 0043-1370), vol. 16, No. 3 (June 1980), pp. 408-413. Copyright, American Water Resources Association, 1980.

The type of treatment is dependent upon the water quality desired and the initial quality of the raw water. For a heavily turbid and contaminated water, a prefiltration or sedimentation process coupled with chemical treatment to remove undesirable chemicals may be required prior to rapid or slow sand filtration, followed by chlorination.

To regulate the water demand and treatment rates, on-side storage is often used. From storage, water is either piped directly to the users or they take their water supply from supply pipes using cans or buckets, which are often dirty and heavily infested with coliform bacteria. The latter type of transmission system is usually used in the village on account of the lower investment cost.

Where water transmission is inadequate or direct pipe connections are not provided, the villagers store their water supplies in containers which are not free of pathogens. Moreover, water is drawn out from the household storage with a dip can or glasses, a process that often results in wetting the user's hand and consequently transferring contaminants (faecal matter) into the water.

2. *Excreta and waste disposal subsystems*

Almost all contaminants and pathogens come from the excreta and waste disposal subsystem, and are either transmitted to human beings directly through the faecal-oral route or indirectly through six major transmission routes:

(a) *Route 1*:

Contaminants→water source→treatment system →on-site storage→transmission system→household storage→kitchen utensils→man. The contaminants enter the water source through agricultural runoff or seepages, or through direct disposal of waste to the water course. These contaminants are, however, removed in the treatment process, the degree of removal is dependent upon the extent and efficiency of the treatment.

(b) *Route 2*:

Contaminants→transmission system→household storage→kitchen utensils→man. With pipes used for transmission, water supply is contaminated through infiltration or seepages from a poorly designed excreta and waste disposal system. With containers (usually buckets or cans), water may be contaminated in one or more of the following ways: containers may contain pathogens in large numbers if poorly cleaned; during its carriage from the supply pipes to the household storage, the containers may be contaminanted with air dust and the resident microbes, both pathogenic and non-pathogenic; and the container may be contaminated by man himself when dirty hands are dipped into the container during the process of transfer.

(c) *Route 3*:

Contaminants→household storage→kitchen utensil→man. Coliform concentration of random water samples collected from storage jars near the Danish farm in north-eastern Thailand have been found to vary from 43 to more than 2,400 MPN (most probable number) per 100 ml. The microbial concentration built up in the household storage was from the first two routes, the bacteria originally present in the storage jar and the pathogens directly introduced by man himself or by animal vectors.

(d) *Route 4*:

Contaminants→kitchen utensils→man. The microbes may be transmitted from the excreta and waste disposal system through various vectors or media. These include insects and animal vectors, contaminanted water used in washing utensils, handling with contaminated hands and microbes from air.

(e) *Route 5*:

Contaminants→food→kitchen utensils→man. The bacterial concentration is practically nil after the cooking process except when food is half-cooked, resulting in only the partial killing or inactivation of the microbes. Contamination may also take place when the food is cooled prior to serving or when served with contaminated kitchen utensils.

(f) *Route 6*:

Contaminants→food→man. This takes place when food like fruits, which do not need cooking, is eaten without thorough cleaning or with dirty hands hands or utensils.

3. *Man and his habits*

Man's sanitary habits are influenced primarily by his benefits, traditions, customs and education. Of all the subsystems, this is the hardest to quantify.

B. DEVELOPMENT OF SYSTEMS DYNAMIC MODEL

A systems dynamic model illustrating the interactions of different parameters involved in rural sanitation was developed to serve as a guide for policy planners in setting forth development plans.

Figure 1 shows the skeletal structure of the model in signed diagraph. It identifies the interrelationship of the different variables in rural sanitation. The arrows in the diagram indicate the direction of influence and the sign (plus or minus) signifies the type of influence. A positive sign denotes that the change in one variable generates a change in the same direction in the second variable relative to its prior value; a negative sign suggests a negative relation, which means that a change in one variable produces a change in opposite direction in the second variable. Applying this concept, the diagram could be interpreted as follows.

Starting from the left of figure 1, it is shown that the coliform origin of the water source is the excreta and waste disposal subsystem. Bacterial transfer could be minimized through good practice of hygiene and sanitation.

Coliform density in water from the source decreases through water treatment, then increases through accumulation in the storage tank and increases further through contamination in the transmission line from a poorly designed extreta and waste disposal subsystem and poor sanitary practices.

Similarly, the MPN index in the household storage increases in the same direction. This concept of parallel increase of coliform density is based on the analysis of random water samples collected for 32 weeks from six central Thai villages and from a village near the Danish Farm in north-eastern Thailand.

In small Thai communities, excreta are used in fertilizing vegetables. Thus, the excreta and waste disposal subsystem is shown to have a positive influence on the build-up of coliform in vegetables. This build-up, however, is inhibited by the environment (especially by the ultraviolet rays of the sun, the desiccation), and is further reduced by proper washing and cooking prior to eating.

The skeletal structure also shows three primary sources of coliform transfer to man: direct fecal-oral route with dirty hands as the vector of transfer, and indirectly, through various media like food and water. It also indicates that the excreta and waste disposal system is the main source of contaminants and pathogens. The raw water source and pipelines may be contaminated by surface runoff and seepages from poorly designed and maintained excreta and disposal systems. In villages where inhabitants collect their water supplies from supply pipes, pathogens may be reintroduced by dirty containers used for collection and by people's dirty hands.

Furthermore, hygiene and sanitation have an immeasurable influence in cutting off the coliform flow lines. The hygiene and sanitation of a certain locality are, however, a function of the villagers' beliefs, traditions, customs and education. These factors are the decelerators of progress of the villages, in cases where these parameters create reluctance among the villagers to accept the advantages of good health and sanitation. For instance, Charnvit reported that the villagers in north-eastern Thailand used treated water for bathing and washing purposes, but preferred raw water for drinking. Education, however, plays a positive role in rural health and sanitation.

1. *Development of DYNAMO model*

The system dynamic model of rural sanitation is shown in figures 2, 3 and 4. The flow diagram portrays the interrelationship of different subsystems shown in figure 1 in terms of the symbols developed by Forester.[1] A list of DYNAMO equations is given by Degoma.[2]

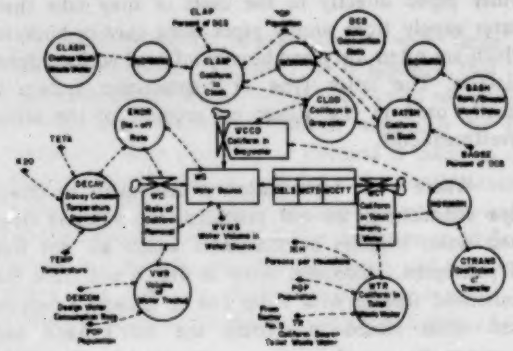

Figure 2. Sector 1: water source

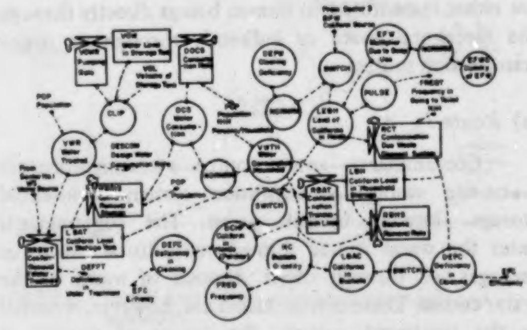

Figure 3: Sector 2. water supply

2. *General assumption of the model*

The model depicts the daily life and activitie of the villagers in central Thailand. Some input dat are, however, based on studies in Bangladesh, th Philippines, north-eastern Thailand and the Unite States of America. The following general assumption were made: (a) the volume of the water source (Cha Phya River) is constant, that is, whatever volume i taken out, is immediately replaced; (b) the coliform density level in the upstream area of the water source has almost the same magnitude as that in the study area, making the contribution from upstream almost negligible; this is possible when the upstream village has the same sanitary characteristics as in the study area; (c) the villagers collect their water supplies from standpipes using buckets and containers; (d) the bacterial die-off rate in the river follows the first order differential equation according to Chick's Law, and the constant used by Marais[3] is applicable; and (e) the excreta and waste disposal subsystem is the only source of coliform bacteria.

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[1] J.W. Forester, *Principles of systems* (New York, Wright Allen Press, Inc., 1968).

[2] E.S. Degoma, *A systems study in rural water supply an sanitation*, Project Report, Asian Institute of Technology Bangkok, Thailand, 1978.

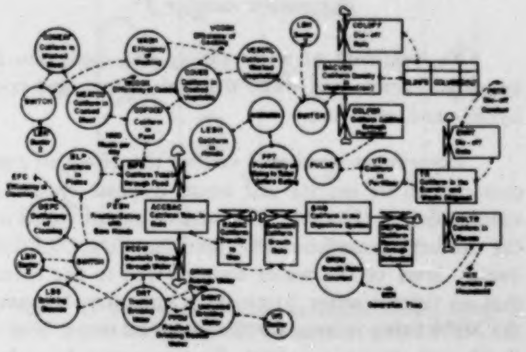

Figure 4. Sector 3: coliform take-in, food and sanitation

C. SIMULATION OF STRATEGIES AND OPTIONS

The model was run batchwise on an IBM 370/145 computer using the DYNAMO II language. The model serves as a planning laboratory where alternative development schemes for a particular village can be examined. In this paper, consequences of alternative strategies for the central Thai villages were investigated and the results are summarized in table 1. Only the Dynamo output of experiment No. 1 (the worst strategy) and experiment No. 5 (the best strategy) are presented in this paper.

Experiment number 1

No treatment of water supply was used, plus a poor excreta and waste disposal system, and poor hygiene and sanitation.

This run uses the assumption and parameter values shown in the lists of equations of the model given by Degoma. The assumptions and parameters generally depict the characteristics of the villages under study, namely: villages 2 to 4 of Tambon Khlongchik, and villages 8 to 10 of Tambon Bangrasan, both in central Thailand.

The results of this run are shown in figures 5 and 6 and the table. Figure 5 shows the variation of coliform density level per unit time in the water source (WS), on-site storage (LBAT) and household storage (LBH), and coliform take-in rate per person per unit amount of food take-in per unit volume of water consumed (BFIR). It may be noted in this run that the coliform density in the water source (*khlong* or canal) ranges from 847 to 44,733 MPN per 100 ml and this increases in the succeeding levels under conditions of no water treatment of any kind. The water quality is at the worst level during rainy days, when runoff is rather high; the best quality is obtained when runoff is at its minimum. That the coliform density level

Table 1. Summary of the results of the experiments

Parameters	*Experiment No. 1*	*Experiment No. 2*	*Experiment No. 3*	*Experiment No. 4*	*Experiment No. 5*
1. WS, MPN/ml	9-447	9-555	0-14	0-14	0-14
2. LBAT, MPN per ml	19-790	0.007-0.2	0-237	0-0.05	
3. LBH, MPN/ml	37-890	12-15	15-592	12-15	0-0.3
4. BIFR, MPN/person-day, 10^4	40-55	40-55	39-40	39-40	0-0.00001
5. RCDW, MPN/person-day, 10^4	1-797	1-4	3-100	1-4	0-0.2
6. ACCBAC, MPN/person-day, 10^4	53-730	45-53	43-210	34-43	0-0.04

LEGEND: WS = Coliform density in water source, MPN/ml.
LBAT = Coliform density in on-site storage, MPN/ml.
LBH = Coliform density in household storage, MPN/ml.
BIFR = Coliform take-in rate through food, MPN/person-day.
RCSW = Coliform take-in rate through water, MPN/person-day.
ACCBAC = Coliform take-in rate, MPN/person-day.

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[3] G.R. Marais, "Faecal bacterial kinetics in stabilization ponds", American Society of Civil Engineering (ASCE), *Journal of the Environmental Engineering Division*, 100(EEI), 1974, pp. 119-139.

does not decrease to zero, even if there is no runoff, can be attributed to the fact that most villagers have no toilet; hence they defecate either in the field or along the *khlong*, causing direct transport of excreta and consequently effecting a high MPN index on the water supply source.

Figure 6 shows the coliform take-in rate (ACCBAC) for the inhabitants. The coliform transfer through water per unit time (RCDW) is higher than coliform transmission per unit time through food (BIFR) because of the high MPN index of drinking water. The coliform take-in resulting from food is highly variable, although it revolves around a constant value. This variability is due to the assumed varying nature of the inhabitants' handling of their food.

Experiment number 2

Slow sand filtration was used for water treatment, a poor excreta and disposal system, and poor hygiene and sanitation.

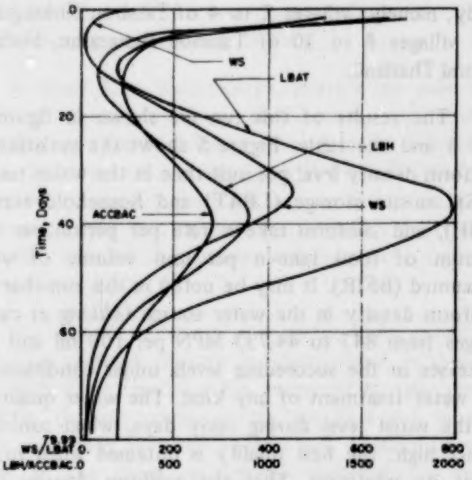

Figure 5. Dynamo output for experiment number 1: WS, LBAT, LBH, and ACCBAC

This experiment investigates primarily the effect of improved water supply quality on coliform take-in rate among the inhabitants. In this run, slow sand filtration is assumed to be the water treatment scheme employed, and the findings of Sirisak (1978) on the coliform removal capability of slow sand filters (99.98 per cent) was used as input data to the model.

Results in the table show that the MPN index initially ranging from 0.76 to 167 MPN per 100 ml at the on-site storage (LBAT) is increased to 1200-1500 MPN per 100 ml, showing the extent of recontamination that has taken place in the transmission line and household storage. The coliform take-in rate (ACCBAC) decreases by 20-60 per cent as a result of water treatment and, consequently, the coliform transmission through food (BIFR) dominates that over water.

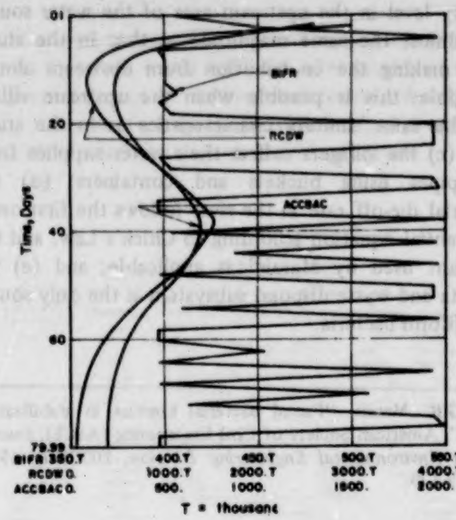

Figure 6. Dynamo output for experiment number 1: BIFR, RCDW, and ACCBAC

Experiment number 3

No treatment of water supply was used, plus an improved excreta and waste disposal system, and poor hygiene and sanitation.

Experiment number 3 verifies the effect of mass construction of excreta and waste disposal system as summarized in the table. The scheme partially cuts off the coliform transmission line, resulting a lower coliform density level of the water source (WS) to the extent that no further water treatment is necessary. However, the MPN index increases and it is as its worst level at the household storage point. Contamination has taken place at the transmission lines and at the household storage (LBH) because of the poor sanitary habits of the villagers. This scheme decreases the coliform take-in rate to a level which is 0 to 5 per cent of that achieved by the construction of a slow sand filtration system.

Experiment number 4

Slow sand filtration for water treatment was used, plus an improved excreta and waste disposal system, and poor hygiene and sanitation.

This experiment verifies the effect of joint construction of a slow sand filtration system and improvement of the excreta and waste disposal system. It is noted from the table that this scheme has almost the same effect as that of experiments numbers 2 and 3.

Experiment number 5

Slow sand filtration was used for water treatment, plus an improved excreta and waste disposal system, and improved hygiene and sanitation.

This experiment illustrates the effect of joint plementation of the sanitation package, in which, cording to figure 7, the coliform density level at water source is at minimum several days after the plementation of the sanitation programme and the ater quality does not change from level to level, licating a total cut-off of the coliform transmission ies. The coliform take-in rate is reduced to zero, us ensuring the health of the rural people from enteric sease infection.

Results of the five experimental runs shown in is paper indicated the need for an implementation of nitation and education programme in conjunction with water supply programme in a village if the health of e rural people is to be improved. Experiments numbers 3 and 4 have clearly shown the interdependence of ese factors in relation to the coliform take-in rate and thus the lack of any one of them would result in the failure of the whole system. Since coliform is an indicator organism for the presence of pathogenic bacteria, a complete removal of the coliform from all transmission routes as previously described is most desirable. Experiment number 5 should be considered as the ultimate goal for any health improvement programme in order to provide maximum benefits to the people concerned and at the same time to optimize the invested capital.

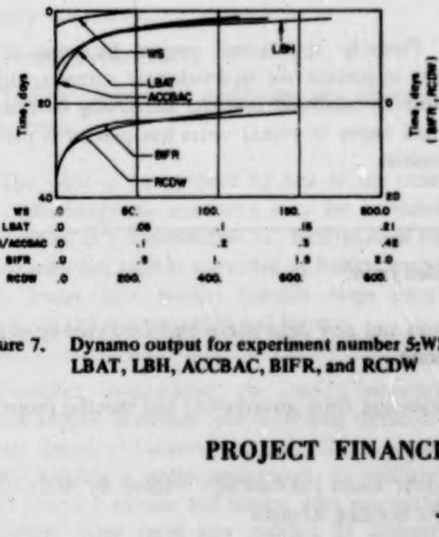

Figure 7. Dynamo output for experiment number 5:WS, LBAT, LBH, ACCBAC, BIFR, and RCDW

D. CONCLUSION

The simulation experiments using the systems dynamics laboratory described in the paper have shown that the development of one particular subsystem such as water supply does not necessarily ensure a solution to the problem of rural sanitation. This is particularly true as the failure of one subsystem, such as the disposal system, even with a success in the water supply scheme, can cause the failure of the total system. It is therefore proper that the development of water supply, a scheme propounded by many international agencies, must be reconsidered to include parallel schemes such as the sociological development of the villagers through education on hygiene and sanitation, establishment of a proper waste disposal system and other related developments, if it is to be a success.

A system dynamic model based on the DYNAMO II language can be very helpful in evaluating parallel and interacting schemes for rural sanitation. Given a certain amount of resources, the systems dynamic model may be used to simulate various combinations of schemes which can bring about the best health benefit to a rural village.

PROJECT FINANCING: PRECEPT AND PRACTICE

*J.G. Warnock**

he problems of financing large hydro projects can only be solved properly by a well-balanced team approach drawing n multidisciplinary sources. A closely integrated approach combined with careful management will encourage the inancial community to invest in a wider variety of projects.

arge hydroelectric projects nowadays present a antalizing mixture of problems and opportunities. lot least is the problem of financing these capital-ntensive undertakings. The opportunity to develop renewable supply of energy has great attraction, articularly in the long term; but long-term borrowings ecessary to finance the venture are not easily come by.

Investment modes have to be found which are appropriate to a capital-intensive, virtually non-escalating, slowly depreciating and thoroughly reliable source of power--hydroelectric development.

In looking at project financing precepts and practice, I outline very generally the principles which have been applied to date and then concentrate on the "ways and means" which I see as being applicable to one of the more demanding approaches to the funding of a large hydroelectric scheme--pure project financing.

From the engineering and management point of view, the following main points are relevant to a hydroelectric project:

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* Vice President and General Manager (Power), Acres merican Incorporated, Columbia, Maryland (USA). This rticle is reprinted with permission from *International Water ower & Dam Construction* (ISSN 0306-400X), vol. 31, No. 8 August 1979), pp. 36-39. Copyright, IPC Business Press Ltd., 9̀79.

- The inherent quality of investment in hydroelectric works cannot be taken for granted. It must be demonstrated case by case to ensure support.

- To build a case for hydroelectric power development requires intensive study on an interdisciplinary basis.

- Studies and financial planning are best assigned to a specially qualified owner's team.

- An important key to success is a highly competent overview, prepared at an early phase of the hydroelectric scheme, updated regularly and kept current as the project proceeds.

- The confidence of the financial community must be carefully nurtured by clear evidence of decisive, well-managed, large hydroelectric projects. There is an obligation on us all to perform with particular distinction.

Small, low-head hydropower plants (by American definition less than 20 m head and 15 MW capacity and, say, about £10,000,000 or $US 22,000,000 capital cost) will be covered in this article as well as large ones, as these may play a significant role in picking up available renewable hydro energy, especially in the United States, where there is a move afoot to add power to any existing dam capable of supporting the investment.

FINANCING METHODS FOR HYDROELECTRIC PROJECTS

Large, giant and jumbo hydroelectric projects usually involve governments, government-owned or government-backed utilities, or, on occassion, a consortium of owners. The difficulties of raising capital for a project consisting of, say, £100,000,000 (about $220,000,000; a typical amount for a large scheme) are substantial, but might on occasion be shouldered by investor-owned interests. The half-billion pound, or the multibillion-pound projects arising nowadays are normally beyond the scope of the private utilities or corporations. Smaller hydroelectric projects can still be handled by individual entities or utilities, and the lengths to which they may have to go to secure the finance they require may present some useful lessons as we attempt to learn more about ways and means of improving the ability to finance larger undertakings.

Financing of hydroelectric schemes may take one of several forms shown in the box.

Properly approached project financing is particularly important for hydroelectric schemes, although it must be admitted that the shortening of maturities of bond issues in recent years has presented particular difficulties.

Form of financing for hydro schemes:	*With funds provided from:*
Normal utility financing	Corporate resources and new debt issues budgeted year-by-year to provide expansion
Development authority financing	Seeded equity financing from government and specific project debt financing
Publicly owned utility financing	Financing with debt issues substantially backed by state or federal government bonding strength
Government appropriation	Budgeted funds for agency development programme, usually on year-to-year allotments, but usually with political support for completion
International lending	Multi-source allotments, usually under World Bank or other leadership. May include long-term credits and some national bank financing
Subsidized financing	Direct grants or low-cost loan funds from government agencies to stimulate supplementary private or other public investment
Project financing	Institutional and private investors with debt service exclusively provided by earnest revenue from contracted supply

BASIC REQUIREMENTS FOR FINANCING METHODS

The hydroelectric power development to be treated for project finance is one which has distinct confines and little in the way of items in common with other schemes (facilities, water use or transmission). Preferably it delivers energy at a well-defined interconnection at which contractual obligations can be precisely measured and monitored. If there should be common use of water, say, from some upstream storage, then a clearly defined operating agreement must be adopted before financing, which covers all obligations and provides for deviations from the contractual base.

When a project is financed, the debt may be serviced in one of several ways. The array of contractual arrangements may include:

- Take or pay contract;
- "Hell or high water": an all-events obligation with "no outs";
- Throughput contract, possibly with a cash deficiency agreement;
- Cost of service tariff;
- Tolling agreement including all charges and standby costs.

The debt to be serviced by one or the other of these basic long-term contracts may be provided by one or other, or a combination of: international banks; large commercial banks; consortia of banks; long-term United States debt market (usually large insurance companies); and export credits and loans.

Complex arrangements are usually necessary to conclude supply contracts and bounding terms of the necessary degree of balanced security. The owner would normally employ a single organization to perform the roles of financial advisor and banker who can act as the intermediary (free from any conflict of interest) in following through negotiations, particularly with the lead interest that emerges from the debt-funding group.

Project financing can sometimes result in a debt/equity ratio which is different from traditional balance sheet financing; and on occasions, 10 per cent equity with the balance met by bank accommodations, earnings during construction and long-term debt has been achieved. Furthermore, project financing may provide a means of "off balance sheet" financing, presenting benefits to a corporation whose financing ratios would otherwise be distorted by a project financing large in relation to normal obligations.

Questions have often been posed regarding the capacity of money markets to accommodate giant or jumbo project financings. Ten years ago, a $1 billion (about £500 million) undertaking was feasible for project finance. Today, projects (mainly in the pipeline field) with capital requirements of $10 billion or more appear to be amenable to this approach. Individual projects of $7-8 billion have already been achieved on the basis of debt service strictly from revenue earned in their operation.

The larger the project, usually, the larger the problem of completion guarantee, which is so often the key issue in any undertaking. At the upper end of the project financing scale, provision of adequate completion security often falls outside the realm of the proponent organization and into that of the end user of the supply, commodity or service. Contractual provisions are possible, whereby the beneficiary of the supply can justify providing assurance of completion on the basis of compensation through a gain of equity in the financed project itself.

Much of the effort involved in the many aspects of the organization, handling and managing of large projects directly and indirectly goes to the task of building confidence in the project: minimizing and defining residual risks, providing for contingency plans and thus "underpinning" the completion guarantee. In the example we shall review, the Churchill Falls Power Development, this basic requirement should become very apparent.

ORGANIZATION OF THE ENTERPRISE

Major projects require a particularly high standard of management competence and engineering input and, above all, a unifying co-ordination at a relatively high level of authority. We see this being provided by an "owner's team": one that is completely identified with the long-term interest of the project owner and is independent in so far as it has no detailed responsibility for such activities as designing, constructing and financing of the project.

The latter responsibility is assigned to the financial advisor/banker. For the other functions, a project management group should be employed, probably chosen by the owner's team and reporting to them. It should be emphasized that the owner's team is not the project management. Setting them apart ensures that all the wider aspects of the project are properly considered by a team which has the time to concentrate on strategic issues and is not weighed down with the day-to-day responsibilities of project management. The bigger, the more risky and the more complicated the project, the greater the need for this division of labour.

The owner's team should be multidisciplinary, with engineering, construction management, marketing, financial, fiscal, insurance, transportation and logistic competence. Furthermore, it must have legal and political expertise.

The team should have a close and harmonious working relationship with the project management who will be called on to assist in and support many of their "owner's" activities. To keep the day-to-day management of the project intact and pursuing its well-defined objectives the project manager may well allocate separate staff resources to fulfill the particular requirements identified by the owner's team.

The main function of the owner's team is the preparation and updating of a continuing project overview. This must cover every significant aspect of the project (technical, economic, marketing, financial, insurance, transport, labour, tax, legal, environmental, political, etc.) plus every significant risk and every significant opportunity, and is the key to the undertaking.

The overview must look at the situation as it affects all the key parties involved: project owners; government; customers; financial interests; insurers; engineering companies; construction contractor; indigenous peoples; conservationists; and regulatory authorities.

It should be prepared as early as is practical in the course of the project, preferably at the concept stage, and then updated regularly until the project is either completed, postponed or abandoned. Yes! abandoned--for one of the prime responsibilities of the owner's team will be to recommend this if circumstances are not, in the over-all context, propitious for the owner to proceed.

The project overview, produced and updated by the owner's team, is thus the key project document for project acceptance, financing and insurance.

ENGINEERING/MANAGEMENT

Participating with the owner's team from the outset of a project can provide the engineer/manager with the complete involvement desirable for the best chance of success. It is preferable for him to be directly involved in the intensive preliminary feasibility studies. The importance of this phase cannot be overemphasized for large hydroelectric projects in need of financing. Time and effort should not be skimped. Reliable data must be generated which stand later tests as the project proceeds; constant revision begets doubt.

As the project financing relies to a substantial degree on "production" and the revenues it earns, the key studies are those pertaining to hydrology, runoff, flow, energy output and optimized capacity. Together with capital costs of construction and estimates of operating costs and replacements, they are the elements on which confidence will be based. This is where the true worth lies of the engineer with a depth of hydroelectric experience, reputation and integrity. He should be brought in to provide a totally reliable basis on which to take the "proceed or abandon" decision.

There are, of course, many other engineering investigations, studies and input on which the confidence in the project is built, geographical, environmental, plant selection, engineering, design, etc. Each element of study and engineering seeks to minimize risk and allow an accurate cost estimate.

We must be aware that, despite the high degree of competence identified with the desirable level of engineering/management, risks will still remain. It is, furthermore, not the role of the engineer, nor of the designer, nor of the manager to assume arbitrary risks. They have the responsibility or courses of action. These risks must then be thoroughly analysed and presented to the owner for his judgement.

It is the owner's team which must decide on vital project issues, and it is the role of the engineer/manager to ensure that all facts are presented in such a way that a sensible and informed decision can be taken. Close integration of the engineer's and manager's roles, as has been achieved in modern project management concepts, has proved to be a most effective method of controlling risks and of achieving the demanding goals set for giant projects.

Identification of risk, eliminating it, controlling it or providing contingency plans are all important elements in the task of building confidence in the security of project financing. At some point, however, the project manager, covering the engineering/management roles and extending these to a whole host of other project implementation functions, has to reach a conclusion on what are the residual risks. Modern techniques are now available to assist in this decision process.

Ten years ago, methods were available by which a variety of approaches to reliabilities of cost and schedule predictions could be matched and the adequacy of contingency allowances assessed. With practice and newer, more advanced technologies, we are now able to offer a much more reliable prediction of uncertainties and to compare relative levels of confidence in, for instance, various segments of an estimate or schedule. In certain cases, residual risks of overrun on large hydroelectric power developments have been quantified. In one case to my knowledge, the process contributed substantially to the project's postponement; insufficient provision for financing the project and its potential overrun could be assured.

PROJECT FINANCING AND THE ENGINEER/MANAGER: AN EXAMPLE

A project of the 1960s presents an excellent example of project financing applied to a very demanding set of circumstances and to an impressive hydroelectric power project with 5,225,000 kW installed capacity and 34.5 GWh energy output.

Churchill Falls involved a total capital cost of some $ 965 million at the 1967 estimate level (well over $ 2 billion at today's values); a project spanning seven years; a labour force peaking at 6,300 and then applying about 150,000 man-hours per month; a project area of 2,500 mi^2; movement to a remote site in Labrador of 0.75×10^6 tons of materials, supplies and equipment; a mammoth undertaking in a frontier environment with many challenges. It has many of the "giant project" ingredients. It demonstrated, with its laudable success, the merits of a multidisciplined overview first adopted at the outset of the project and then continued as a technique for ensuring confident management throughout.

THE NEED FOR A COMPREHENSIVE OVERVIEW

Churchill Falls Power Development provides a good example of the roles recommended for successful undertaking of large hydroelectric schemes: the owner's team; the engineer/manager; the financial advisor. The owner's team was largely provided from the experienced ranks of Rio Tinto Zinc; they appointed a joint venture, Acres Canadian Bechtel, to the role of manager of engineering and construction, and Morgan Stanley was selected as financial advisor.

A key element of the project overview was the wide-ranging documentation produced to support the bond-offering memoranda prepared by the financial advisors. This proved to be invaluable both to the financing and subsequent implementation of the undertaking.

Early in May 1967, 30 days after the project release date, it became apparent that the size of the first mortgage bond offering was such that the owner, Churchill Falls (Labrador) Corporation (CFLC) would have to go to unprecedented lengths in presenting an unquestionably high degree of confidence in all aspects of the project.

It was decided that financing documentation would be produced for Churchill Falls which left virtually no questions unanswered. The completeness of the power contract provisions, adequacy of engineering designs, reliability of construction cost estimates, adequacy of escalation and contingency provisions, security of schedule, were all to be supplemented with detailed documentation setting out the approach and the contractual policies to be adopted by CFLC. The contract packages in which the work was to be assigned, the principles and basis of the "no strike, no lockout" master labour agreement, the insurance provisions and the steps that were to be taken to meet all statutory obligations of the Province of Newfoundland/Labrador were also to be treated in detail. In addition, reports, plans and estimates were required for the permanent townsite facilities, the costs of maintaining this and the cost of operation and replacement expenditures. Management information systems were to be clearly defined and outlined.

To defuse potential questions concerning reliability, cost and schedule performance of the contracting industry, a review was made of experience on large civil engineering capital projects throughout Canada in the 10 years preceding 1967. It was recognized, too, that the general economic activity in the country at large, and particularly in eastern Canada, could have a significant bearing on the availability of adequate contracting forces and on the competitiveness of bidding; a comprehensive project economic review was therefore commissioned.

The impact of future nuclear power generation on system energy costs was still another question that had to be addressed. A study was made of the likely trends in nuclear generation capital and operating costs over the 40-year term of the power contract envisaged for Churchill Falls.

A final document in the bond-offering support series related to the assessment of project contingencies. A rigorous analysis was made of risks to which the project was exposed, and a comparison made between the financial implication of these and the contingencies provided in the capital cost estimate.

The documentation had a wide variety of benefits. It was very useful, for instance, to the insurers who played a significant role in certain aspects of its preparation. The project tested the capacity of the insurance market then available to cover the maximum foreseeable loss. The support documents provided a convenient means of preparing subsequent "overviews" to test the credibility and confidence of the project as it proceeded. Furthermore, it provided a disciplined approach for the project management group who employed it to its full benefit.

CONCLUSION

The example reviewed of the financing of a major hydro scheme illustrates the important role of the engineer/manager. Several points appear worthy of note in drawing conclusions:

– the need for an unquestionably high degree of technical skill and experience to support the undertaking,

– ability to provide engineering properly related to project need;

– provision of design with sufficient degree of conservatism to build confidence;

- flexibility to adjust engineering approach to best interest of owner and project;

- close interaction with construction management to achieve optimum costs;

- active participation in construction policy and contract packaging consideration;

- ability to identify, analyse risk and provide compensatory measures;

- close interface with insurance and financing sectors to build confidence;

- ability to work effectively in a project management system;

- high-quality field engineering to ensure quality and cost control;

- ability to judge future operation requirements and assess costs;

- continuing involvement in project overview reporting.

Properly applied, these "requirements" can do much to secure a highly successful project which will engender confidence from the financial groups involved. If several major hydroelectric projects can be completed with true distinction in this period of sensitivity in the money markets, a new level of interest may be generated in the type of long-term financing required by large hydroelectric projects. There will certainly be opportunities and need for some innovative approaches.

THE ROLE OF INTERNATIONAL LENDING AGENCIES

*T.W. Berrie**

Unless the financing agencies are approached in a proper manner, the scheme may never come to fruition. An understanding of the way in which international agencies operate is essential for builders, contractors and engineers.

Even the best-designed and the most economically justified hydropower scheme is not built unless finance for it (foreign exchange and local) is made available. Because normally hydro projects are very capital-intensive, especially with respect to foreign exchange, this requirement for finance can be a serious problem.

Dam engineers, having always experienced "budgetary control" (sharing to a budget allocation), are usually now also very conscious of using the most economic (i.e. cost-effective) design. Their designs have also had to be fitted into the economics of irrigation, power, navigation systems; and, in later years, development plans for the whole economy.

Finance, the final link in the chain towards a successful project, is currently perhaps the single most important constraint. This is mainly because of the changing circumstances for obtaining finance for projects, and the drying-up of the total amount of finance available. Whether they like it or not, engineers must face up to this outstanding problem, and to the concomitant problem of dealing with the international agencies, which influence such a large part of the modern financing process.

FINANCE REQUIRED FOR HYDRO PROJECTS

Over the 10-year period 1975 to 1985, one estimate puts the total volume of finance required for electric power at about $US120 billion (1978 price levels) for the developing countries as a whole. About $16 billion of this is expected to be required for hydroelectric projects. Many hydroelectric projects are multi-purpose schemes catering for electricity and irrigation, amongst other uses of somewhat lesser importance. About as many hydro projects are required for irrigation alone as are required for several purposes. This means that about $32 billion is expected to be required for hydro projects, in the period 1975 to 1985, in so far as the developing world is concerned—a considerable volume of finance for what is, after all, a relatively small part of the total planning requirements of the developing countries.

During the period 1965 to 1975, the equivalent figure was only about $20 billion (1978 price levels), partly because of the (then) low cost of energy. A very rough correction to this figure, to allow for the high cost of energy in the modern world, increases the $20 billion to about $25 billion. There has still been, therefore, a considerable increase in the amount of finance required for hydro projects (in real terms) over the last ten years; this amounts to about a 33½ per cent increase; and, unless nuclear power comes on stream in developing countries to a much greater extent than it is now, by 1985, the increase for the period 1975 to 1985 could well be half as much again in real terms.

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* Senior Consultant, Preece, Cardew and Rider, Brighton, England. This article is reprinted with permission from *International Water Power & Dam Construction* (ISSN 0306-400X), vol. 31, No. 8 (August 1979), pp. 27-30. Copyright, IPC Business Press Ltd., 1979.

WHERE THE FINANCE WILL COME FROM

The majority of this finance required for hydro projects in developing countries in the future must come, as in the past, from the developed world. Even if it is assumed that all financing for such projects will be based on non-commercial motives, that is, with no regard to return on capital at all (a very unreal assumption), it would be difficult for developed countries to keep up the volume of their loans/credits, for all are experiencing difficulty in increasing growth, in real terms, to any large extent. This results partly from a still (1968 onwards) unbuoyant world trading situation, but partly also from other factors, e.g. the entering into a "high-cost-of-fuel" era from a "low-cost-of-fuel" era; and there are other factors.

During the period 1961 to 1975, the developed world increased its gross national product (GNP) by 80 per cent in real terms— and yet overseas development aid hardly rose at all in real terms. In 1975, the netflow of economic resources to developing countries amounted to $47 billion. In 1976, the Development Aid Consortia (DAC) countries, combined, provided $41 billion, and the Organisation of Petroleum Exporting Countries (OPEC) provided a further $7.5 billion. This amounts to no growth in real terms.

With the continuing increase in requirements for finance for projects of all kinds, therefore, developing countries raised $22.5 billion on the Euro-currency markets, a very large increase in this expensive and relatively short-term repayment finance.

Reliable figures on the extent to which all these financial flows were used for hydro projects are not available. However, some examples show that the extent might well be considerable. Foreign capital flows have historically provided about 80 per cent of the foreign exchange required for electric power expansion, and about 65 per cent of the foreign exchange requirements for expansion in the irrigation sector. For the World Bank alone, power sector lending accounted for a cumulative 20 per cent of total lending by the first half of the 1970s, while the irrigation sector accumulated about 8 per cent of total lending by the same date. These indicate that financial flows for hydro projects may have been considerable.

The United Nations says that a minimum figure of 1 per cent of GNP (known as the "target for development") devoted to development aid to less-developed countries, is necessary to make any progress. Although this seems a very small amount, this has by no means been achieved. The achievements of official (bilateral and through the World Bank, etc.) aid has fared even worse. This failure of official aid to achieve its target has thrown a greater burden on the commercial agencies, both national and international. Commercial aid services are becoming more and more expensive and scarce.

It is thus into the hands of international multinational agencies that public debt service is being rendered in developing countries (preliminary figures outlined by OECD in May 1979 indicate that this trend is accelerating). Multinational lending agencies mean the World Bank and the other 39 similar agencies.

For hydro projects requiring large amounts of finance, commercial terms are becoming prohibitive, bilateral official loans more scarce. Their finance is therefore increasingly from multilateral institutions, making life more difficult from the financing point of view in many ways, as will be explained next.

"INTER-NATION" PRIVATE BANKS AND EURO-CURRENCY MARKET

Private finance is usually from private banks and the Euro-currency markets. With respect to hydro projects, loans from private sources are far from ideal and can be, under certain circumstances, financially quite disastrous. This is because the asset lives for hydro project works may well be as long as 50 years; whereas the repayment of the loan may well be expected over the period of 7 to 9 years for private loans, as against 20 years for multilateral official aid; the period for repayment of bilateral official aid can be as long as 50 years, i.e. matching the asset life.

Also the interest burden for the private banks and Euro-currency loans can be quite crippling, at 9 to 10 per cent, compared with rates as low as 0 per cent for official aid.

On the whole, the terms of multilateral official aid are prefereable to those of private aid, if official bilateral aid is not available. The interest rates tend to be smaller and the repayment period longer. With the drying up of bilateral official aid and the crippling debt caused by private loans, the Governments of developing countries are being forced to turn more and more to multilateral official agencies, such as the World Bank, to finance hydro projects. As will be seen in the next section, compared with private and bilateral aid conditions, multilateral aid conditions can be very onerous, both for loan agreements and the pre-project appraisal requirements.

LENDING CONDITIONS FOR MULTILATERAL AGENCIES

The requirements for lending of the World Bank (and those of complementary banks differ little in principle) are given comprehensively in its publications. The bank requires a rigorous technical, economic, financial and managerial appraisal to be made, not only of the project itself, but also of the development programme of the sectors concerned. It requires a financial feasibility test to be applied to any utility/agency involved. Under its loan agreements, that utility/agency must inform the bank of any investment made, whether it be associated with a bank-funded project or not. The same loan agreements lay down quite specific financial performance tests which must beattained. Above all, the bank often assumes the right to supervise the appointment of consultants and contractors, to insist on international competitive bidding for con sultants and contractors, to insist on international competitive bidding for consultants and goods, and to supervise the building works/studies involved, throughout the whole time of the loan repayment period.

Such actions may or may not be justified. The World Bank calls itself the "bank-of-last-resort", i.e. it encourages others to go elsewhere for finance if they possibly can; for if they cannot, then the full appraisal system of the bank will be brought to bear on the possible borrower. Wishing to return to the day when bilateral aid gave relatively easy-termed (every way) assistance, the prospective borrower for a large hydro project, involving many hundreds of millions of dollars, must yet be content with his lot. That is, he cannot afford the debt-service of private finance so he must approach these multilateral agencies more and more; and learn about them.

Water Resourcefulness Department

WATER IN . . .

"Super Slurper", a starch-derived absorbent that swells as it jells, has been pressed into service to stabilize and revegetate disturbed soil.

Depending upon the chemical purity of the water with which it is mixed, the slurper can swell from a few hundred to 1,000 times its weight. Put into more practical terms, treating a sandy soil with 0.2 per cent by weight of super slurper will give it about the same water-holding capacity as the best Corn Belt soils.

Because of this characteristic, super slurper has become the key ingredient in many proprietary products–including those used in soil conservation–since its development in May 1973 by the US Department of Agriculture's Northern Regional Research Center at Peoria, Illinois.

Major conservation uses include hydromulching and hydroseeding grass onto disturbed land. In hydromulching, the slurper is mixed with water and a fibrous mulching material, usually hay, straw, or wood or paper fiber. Estimates are that up to 10 million acres of disturbed US land annually require such seeding, including roadsides, mine spoils, shopping centers, athletic fields, power lines, airports, dams, levees, and similar projects.

Use of the slurper in hydromulch products greatly improves seed germination by holding water in the root zone instead of allowing it to soak deeper. The slurper also acts as a highly effective binder or tackifier that keeps mulching material from washing or blowing away.

The present cost of pure super slurper for bulk users ranges from $US2.50 to $3 a pound. But prices are expected to decline substantially as production increases. New uses for super slurper in industry and agriculture are reported constantly, so much so that it is impossible to envision the variety and extent of its ultimate usefulness, the Northern Regional Research Center comments.

-- From *Soil and Water Conservation News* (USA), April 1980

. . . AND WATER OUT

A new system to dewater clays, mill slimes, and solid wastes such as sludges or phosphate tailings where solids are suspended in liquids is under development by researchers at Battelle's Geneva, Switzerland laboratory. The alternative to conventional filter presses and belt-pressure dewatering processes is expected to result in savings in product, labor and operating costs.

The new technique combines the effects of an electric field and hydrostatic pressure. When a solid/liquid suspension is fed continuously on top of the filtering unit by two vertical, moving belts--which serve as cathodes--an electric field forms that allows removal of the water by electro-osmosis. The positive pole, or anode, also attracts charged solid particles resulting in a thick accumulation or solid "cake." The effect of the electric field is enhanced by hydrostatic pressure, improving filtering efficiency as the cake descends and thickens.

Evaluations have been conducted on a small pilot unit using wet clays with a 70 per cent moisture content. A 25 per cent reduction in moisture content in the clay was found in the discharged cake form. Filtration output of the pilot unit is in the range of 30 to 40 kilograms of dry matter per square meter per hour, comparable to performances of filter processes. Patent applications on the system are pending in the United States and several other countries.

-- From *Water Newsletter* (USA), 15 May 1981

RESEARCH

HYDROGEOLOGIC EVALUATION OF WETLAND BASINS FOR LAND-USE PLANNING

*Arnold L. O'Brien and Ward S. Motts**

Motivated by suburban encroachment into and near wetland areas, 23 of the United States of America have enacted legislation to protect the public from flooding, pollution and loss of water resources which may be attendant upon development in wetlands. There is, however, a growing awareness that wetlands are not a homogeneous class but occur under a wide variety of geologic, hydrologic, and topographic conditions and may, in fact, exhibit a range of hydrologic responses. The central problem, therefore, is to define those conditions that will allow meaningful distinctions among wetlands. The authors propose a wetland evaluation system to aid in land-use planning and to further our knowledge of wetland hydrology. The data and information in this report is drawn from the authors' participation in a four-year wetland research project (Water Resources Research Center, University of Massachusetts, Amherst; Grant No. OWRR, WR B-012 and WR B-023) and from additional detailed studies of numerous New England wetlands for towns.

Although many wetland classifications have been developed (c.f. Cowardin *et al.*, 1977; Zoltai *et al.*, 1975), they deal primarily with ecological aspects rather than hydrology. A wetland classification based on factors which modify hydrologic response would provide a framework to better evaluate existing studies. Moreover, it would serve to focus research needs and would provide a valuable aid in land-use planning.

A. Role of wetlands

Wetlands are generally defined as those lands which are periodically flooded or which have ground water at, above or near the surface for a major part of the year. In addition, they are commonly floored with organic deposits such as peat and muck, and are characterized by a distinctive suite of plants. As a purely hydrological definition, the most significant component is the level of ground water. Flooding and a characteristic vegetational suite, although important for mapping purposes, are conditions commonly subsequent to a high water table.

There has been a tendency to consider the wetland as an isolated entity with little relationship to its basin. However, the true significance of wetlands is only apparent when considered in relation to underlying aquifers and the regional hydrology. Wetlands play distinct roles in the hydrogeology of basins, and thus influence land-use decisions. First, wetlands modify run-off in the following ways: reduction of flood peaks, modification of low flow, effect on seasonal run-off and effect on water quality. Second, there is the recharge/discharge relationship of the organic mat and the associated hydrogeological relationship with the underlying aquifer. Third, there are problems of ground-water development in wetland basins (associated with adequate transmissivity, saturated thickness, recharge and water quality). These roles become significant when considering demands for land use such as modification of regional hydrology or well field development of the underlying aquifer. However, the hydrologic linkages between wetlands and aquifers are the primary conditions common to all land-use decisions. Consider, for example, a wetland underlain by an artesian aquifer of high transmissivity in which there is upward vertical leakage from the aquifer into the organic deposit. This area would be of interest because it has a high water-supply potential and because the artesian leakage could be expected to have an impact on the entire run-off pattern.

Such diverse roles necessitate the consideration of a wide range of factors which produce significant hydrologic responses. In the following sections we present these factors. This review is intended to provide a framework for future research.

B. Significant factors of wetland basins

Wetlands are composed of organic deposits which develop in response to the occurrence of ground water at, or near, the land surface for a major portion of the year. The resulting organic mat and associated flat topography exert an influence on the regional hydrology and on water quality, and may also place constraints on hydrologic development. The wetland, however, is but part of a larger basin and can only serve to modify the hydrologic character of that basin. This paper, therefore, identifies a variety of basin-wide factors which may either be the direct effect of an organic mat or may be modified by it. These factors are grouped into three principal categories (geologic,

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Significant wetland factors

1. Geologic factors
   - (a) Surficial material
     - (i) Till
     - (ii) Stratified drift
     - (iii) Lakebed
     - (iv) Alluvium
   - (b) Thickness of surficial material
     - (i) Less than 25 feet
     - (ii) Between 25 and 50 feet
     - (iii) Greater than 50 feet
   - (c) Bedrock
     - (i) Igneous and metamorphic bedrock
     - (ii) Sedimentary bedrock
2. Hydrologic factors
   - (a) Hydrologic position
     - (i) Perched wetland
     - (ii) Water-table wetland
     - (iii) Water-table/artesian wetland
     - (iv) Artesian wetland
   - (b) Permeability of the organic layer
     - (i) High permeability (generally associated with peat)
     - (ii) Low permeability (generally associated with muck)
   - (c) Depth of water in the wetland
     - (i) Water stands above the surface
     - (ii) Water lies below the surface
   - (d) Transmissivity of aquifer
     - (i) Low transmissivity (less than 10,000 gpd/ft)
     - (ii) Moderate transmissivity (10,000 to 40,000 gpd/ft)
     - (iii) High transmissivity (greater than 40,000 gpd/ft)
   - (e) Ground-water outflow
   - (f) Water quality
     - (i) Water on the wetland surface
     - (ii) Water in ponds and streams associated with the wetland
     - (iii) Water in the organic deposits
     - (iv) Water below the organic deposits (unconfined zone)
     - (v) Water in deep artesian aquifer
     - (vi) Water in bedrock
3. Topographic factors
   - (a) Topographic position
     - (i) Wetland lies near mouth of basin
     - (ii) Wetland located on the floodplain
     - (iii) Wetland near the basin divide
   - (b) Wetland size

hydrologic, and topographic) which are summarized in the table.

1. *Geologic factors*

The identification of geologic factors is especially suited to reconnaissance surveys and preliminary evaluations as the units carry inferred hydrologic characteristics. A knowledge of geologic units is important in determining water supply potential and is an aid in assessing run-off characteristics for the basins. For example, high hydraulic conductivity combined with adequate saturated thickness in either bedrock or surficial materials are important indicators of water-supply potential and, if combined with adequate recharge, may produce sustained flow during the dry season. The surficial material on which wetlands of the north-east are situated include the following.

(a) *Surficial material*

- (i) Till (generally low yields of water);
- (ii) Stratified drift (high to moderate yields of water);
- (iii) Lakebed or other confining bed underlain by high-yielding artesian aquifers (high to moderate yields of water);
- (iv) Alluvium (low to moderate yields of water).

These types are drawn from a survey of Massachusetts wetlands (Motts and Heeley, 1973; Heeley and Motts, 1976) and are similar to a classification originally proposed by Baker (1960).

(b) *Thickness of surficial material*

Further definition should focus on the thickness of the surficial material and the nature of the bedrock. The following categories and associated water yields are based on the authors' experience with New England aquifers (Motts and Heeley, 1973; Heeley and Motts, 1976).

- (i) Saturated thickness < 25 feet (generally these aquifers will produce only small quantities of water);
- (ii) Saturated thickness 25 to 50 feet (the aquifer may produce moderate to high quantities

of water, depending on the average hydraulic conductivity and saturated thickness);

(iii) Saturated thickness ⟩ 50 feet (the aquifer has excellent possibilities of producing large quantities of water).

(c) *Bedrock*

Bedrock should also be identified according to the following categories.

(i) Igneous and metamorphic rock contain fracture porosity and commonly yield small quantities of water to wells. They usually admit only small ground-water exchange with the overlying surficial aquifer;

(ii) Sedimentary rock contains intergranular, fracture, or solution porosity and may yield large quantities of water to wells; ground-water exchange potential may be great.

The hydrologic connexion between wetlands and bedrock may be very significant. For example, in certain cases the permanence of wetlands (i.e. their tendency not to dry up) may be a function of discharge from bedrock with high transmissivity combined with extensive recharge areas.

2. *Hydrologic factors*

Factors related to water quantity and quality are grouped under this heading and, as with the geologic factors, are not restricted solely to measurements which relate directly to an organic mat. Some of the factors included here may be critical to an understanding of hydrologic response of the wetland basin, whereas others may be related to ground-water development. The variety of factors presented is a reflection of the diverse interests centered on wetlands or their basins.

(a) *Hydrologic position*

This factor classifies the wetland according to its relationship to the principal zone of saturation (see figure 1). Wetlands perched above the main zone of saturation are commonly in a position to recharge the regional aquifer whereas those that are in contact with the main ground-water zone generally serve as a discharge area for the regional aquifer.

(i) Perched wetland (wetland perched above a principal zone of saturation);

(ii) Water table wetland (wetland intersects thick unconfined main zone of saturation);

(iii) Water table/artesian wetland (wetland intersects thin unconfined zone underlain by a confining bed which in turn in underlain by a major artesian aquifer which "feeds" the shallow unconfined zone);

(iv) Artesian wetland (wetland rests on confining bed and is "fed" by artesian water flowing through the confining bed).

Types (i) to (iv) are part of a continuum in which the wetland is respectively elevated above, or depressed below, the regional potentiometric surface. In the annual cycle, some wetlands may be only slightly depressed beneath the regional potentiometric surface during the wet season, but become perched as the regional potentiometric surface declines (c.f. O'Brien, 1977). Types (iii) and (iv) have been found to be common and distinct types in Massachusetts (Heeley and Motts, 1976).

(b) *Permeability of the organic layer*

There is little research as yet on the manner in which permeability of the organic deposits influences hydrologic function. Water tables in the wetland, however, are coincident with the organic mat, so the potential for hydrologic control is great. Presumably this factor influences run-off following a storm and controls, in part, ground-water discharge rates (c.f. O'Brien, 1977; Gorham and Hoffstetter, 1971). Important distinctions may be as follows.

(i) High permeability (greater than 10 gpd/ft horizontal permeability in the water-conducting zone; generally associated with peat);

(ii) Low permeability (less than 10 gpd/ft horizontal permeability in the water-conducting zone; generally associated with muck).

A permeability value of 10 gpd/ft was selected as an appropriate division because it seems to reasonably

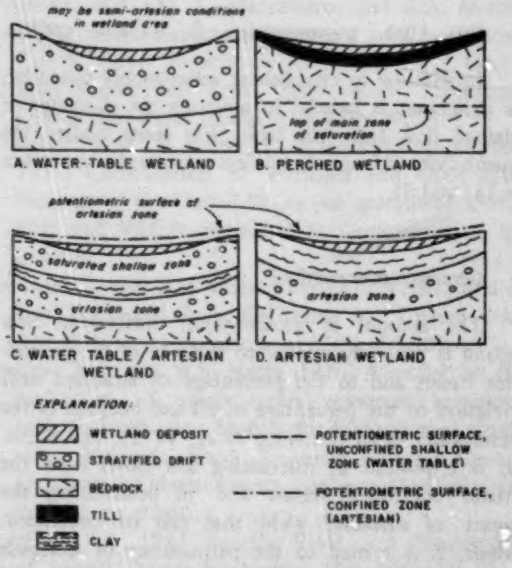
may be semi-artesian conditions in wetland area
top of main zone of saturation
A. WATER-TABLE WETLAND
B. PERCHED WETLAND
potentiometric surface of artesian zone
saturated shallow zone
artesian zone
artesian zone
C. WATER TABLE / ARTESIAN WETLAND
D. ARTESIAN WETLAND
EXPLANATION:
WETLAND DEPOSIT
STRATIFIED DRIFT
BEDROCK
TILL
CLAY
POTENTIOMETRIC SURFACE, UNCONFINED SHALLOW ZONE (WATER TABLE)
POTENTIOMETRIC SURFACE, CONFINED ZONE (ARTESIAN)

Figure 1. Wetland relationships to the principal zone of saturation (hydrologic position)

separate data from field measurements into two groups (Boelter, 1965; O'Brien, 1977; Sammel *et al.*, 1966). Also this is the lowest permeability limit for aquifers (Johnson, 1967).

(c) *Depth of surface water in the wetland*

The depth of standing surface water in wetlands may be classified as follows.

(i) Water stands above the surface during the greater part of the year;

(ii) Water lies below the surface during the greater part of the year.

In certain types of wetlands, such as the marshes and wet meadows of the north-east, water commonly stands above the surface for the major part of the year. In other wetlands, for example the swamps and bogs of the north-east, water is below the surface during the growing season. The seasonal water level is, of course, an important determiner of the vegetation assemblage but, more importantly, it governs the hydrologic response of the wetland.

(d) *Transmissivity of aquifers underlying wetlands*

Transmissivities described below occur in unconsolidated sediments above bedrock and should be determined for both the unconfined and confined aquifers. These values are chosen primarily because of their value for water-supply studies and land-use planning purposes.

(i) Low transmissivity (< 10,000 gpd/ft);

(ii) Moderate transmissivity (10,000-40,000 gpd/ft);

(iii) High transmissivity (> 40,000 gpd/ft).

In addition to establishing water-supply potential, this parameter is helpful in assessing the character of sustained flow from the basin. For some studies, the transmissivity of bedrock aquifers may also be important (see 1a i and ii).

(e) *Ground-water outflow*

The amount of ground-water outflow in New England is primarily related to the size of the ground-water basins and to the percentage of stratified drift in relation to the percentage of till and bedrock in the ground-water basin (Cervione *et al.*, 1972). This condition is important in forecasting low flows from the wetland controlled basins and in determining the amount of sustained yield that can be developed. Further, it is related to the permanence of wetlands and is an important element in the determination of a hydrologic budget for the wetland basin.

(f) *Water quality*

Differing water quality may be found in six distinct zones in the wetland basin. All zones form an interacting hydrochemical system; heavy withdrawals from any zone may cause encroachment and a consequent change in quality of the water withdrawn from the desired zone.

(i) Water on the wetland surface;

(ii) Water in ponds and streams associated with the wetland;

(iii) Water within the organic deposits;

(iv) Water in the unconfined zone below the organic deposits;

(v) Water in deeper artesian aquifers (as in 2a iii and iv);

(vi) Water in bedrock below surficial deposits.

3. *Topographic factors*

Topographic factors relating to position and size may be of considerable value for flood hazard planning and hydrogeological evaluation.

(a) *Topographic position*

The ability of a wetland to modify run-off from the basin and the recharge/discharge function depends, to a significant degree, upon its topographic position (see figure 2). For example, a wetland near the mouth of a basin is in a position to control run-off from the entire basin, whereas wetlands near the basin divide can only impact a small fraction of the run-off. Also, wetlands on the basin perimeter occupy the basinal recharge zone while those at the mouth occupy the discharge zone.

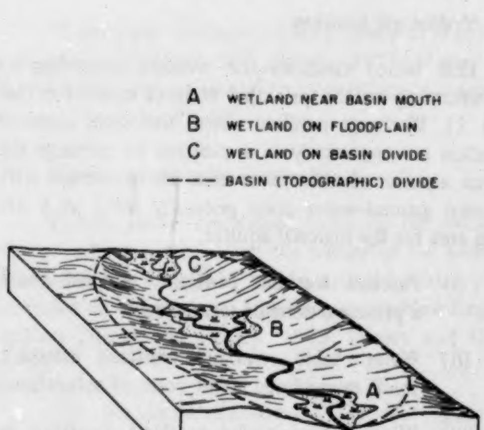
A WETLAND NEAR BASIN MOUTH
B WETLAND ON FLOODPLAIN
C WETLAND ON BASIN DIVIDE
BASIN (TOPOGRAPHIC) DIVIDE
C
B
A

Figure 2. Schematic diagram showing topographic positions of wetlands

(b) *Wetland size*

Both absolute size and size relative to the drainage basin should be considered. Although it is generally assumed that the larger the wetland, the greater the modifying effect, some cautions may be in order. First, it is possible that a very large wetland will behave differently from a similar but smaller wetland, so that concepts of similitude do not apply In other words, size may bear a non-linear relationship to hydrologic response, so that a doubling of wetland area may more than double its potential for hydrogeologic modification. Second, it may be important to determine the size of the wetland in relation to the ground-water basin as opposed to the topographic basin. This could be significant distinction for wetlands that receive water from deeper artesian aquifers.

C. Hydrogeologic classification

A goal of this paper is to establish a wetland evaluation system that assists in assessing hydrogeologic value and land-use decisions. Such an evaluation system is difficult, however, because of the numerous variables that are involved in wetland hydrogeology and because of the different ways that wetlands are viewed by people with different interests. It may be desirable to have several classifications, depending on the particular value that is sought in a wetland or group of wetlands.

Eleven factors and 29 subfactors have been presented in this report (see the table). These allow a very large number of wetland hydrogeologic profiles to be described, but only a fraction would represent realistic combinations. Such combinations should be identified and tested to allow the construction of a sound hydrogeologic classification for wetlands.

One recommended classification for the purpose of defining hydrologic responses for north-eastern wetlands may be constructed from parameters1, 2a and 3a, as shown in figure 3. Two major geologic types have been formed through a synthesis of the geologic factors presented above. Geologic type I (bedrock overlain by till or alluvium) would be expected to contribute only small quantities of ground-water to the wetland while geologic type II (stratified drift) could contribute large quantities of ground water. The wetland would further modify flow from the basin through a combination of its hydrologic and topographic positions. The resulting matrix produces 24 categories, 13 of which are common types. These should be further tested to additionally define their hydrologic function in this classification.

Similar combinations of other factors may prove useful in developing additional classifications. Such further definition of the function of the wetland may lead to the quantification of significant factors and the ultimate ability to map hydrologic types and their significance.

GEOLOGIC TYPE I

BEDROCK OVERLAIN BY TILL OR THIN ALLUVIUM

II Hydrologic Position

III Topographic Position	A Perched Wetland	B Water - Table Wetland	C Water - Table / Artesian Wetland	D Artesian Wetland
1 Wetland near Basin Mouth	*com*	*com*		
2 Wetland on Floodplain	*com*	*com*		
3 Wetland on Basin Divide	*com*	*com*		

GEOLOGIC TYPE II

STRATIFIED DRIFT

II Hydrologic Position

III Topographic Position	A Perched Wetland	B Water - Tcble Wetland	C Water - Table / Artesian Wetland	D Artesian Wetland
1 Wetland near Basin Mouth		*com*	*com*	*com*
2 Wetland on Floodplain		*com*	*com*	
3 Wetland on Basin Divide	*com*	*com*		

com = common

Figure 3. One recommended classification for the purpose of defining hydrologic response for northeastern wetlands constructed from parameters I, IIA, and IIIA.

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DRAINAGE NETWORK POWER

*K.J. Gregory**

A large number of research investigations have related indices of drainage basin character to measures of water and sediment yield. Such indices of basin character include measures of the topographic characteristics, the rock and soil types and the vegatation and land use of the basin. The objective of the models produced is to be able to estimate flow characteristics from watershed parameters. Thus, in a study of twelve basins in West Virginia, Chang and Boyer (1977) related low flows to watershed and climatic parameters. They concluded that meaningful low-flow estimates can be obtained from watershed parameters alone in a mountainous humid region. The watershed parameters that they used in the final model were watershed perimeter, main channel length and a watershed form factor. A recent study by Patton and Baker (1976) concluded that morphometric parameters, including drainage density, stream magnitude and relief ratio, are practical measures of flood potential in basins smaller than 100 mi^2 in area. They identified ruggedness number, the product of relief and drainage density, as the variable which summarizes the interaction of the two most distinguishing variables from those selected. Parameters estimated for the Kentucky watershed model (Magette *et al.*, 1976) also included the product of drainage density and a compactness coefficient as one of the independent variables in the multiple regression equations proposed.

Where several variables are employed in a multiple regression equation, it is not easy to interpret the significance which the variables have collectively. Therefore in several recent studies it has become apparent that a few meaningful indices may be more useful, easier to interpret and easier to measure than a larger number of intercorrelated variables (Gregory, 1977a), and so it is desirable to develop indices which have a physical significance. The drainage network affords a possible basis for the calculation of significant indices because the network responds to the climatic characteristics of the basin and also reflects the soil, rick types, vegetation and land use and the topographic nature of the basin. The drainage network can therefore be regraded as a sensitive indicator of many other watershed and climatic characteristics. For this reason the drainage network should provide the means for the development of a significant index of watershed character and, accordingly, the fundamental importance of the drainage network has been recognized by many authors, including Gartsman *et al.* (1973). Black (1970) also discussed the fundamental importance of the drainage network but he noted that despite the significance expected intuitively of an index based upon the drainage network, this significance had not convincingly been demonstrated in the many studies already completed. This lack of the progress expected may reflect the fact that drainage density values have not always been interpreted as representing a dynamic feature of the drainage basin. The drainage network expands and contracts and it is this dynamic feature which contributes to the determination of discharge characteristics. Care has to be given not only to the sources of the drainage density values but to the physical significance which the values may have and to whether the same values are equally relevant to different flow indices.

The fundamental importance of the drainage network arises because water flow in channels is more rapid than water flow over, or through, slopes. However, the index of the drainage network most frequently used is drainage density, which simply indexes the relative length of channel flow. The character of the drainage network also embraces the features of pattern, of channel size, and of the relief dimension. The arrangement of stream channels is particularly likely to influence peak streamflow because a compact arrangement of channels will allow a smaller time of concentration than an elongate network. This feature of the drainage network has often been expressed indirectly by a measure of watershed shape. Continuing progress from the topological analysis of drainage networks may allow developments from this approach and

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Data for 14 watersheds shown in figure 1, employed in analysis for figure 2

Watershed	*Drainage area (km^2)*	*Mean annual precipitation 1916–1950 (mm)*	*Relief of basin (m)*	*Drainage network power (m^3/m)*
Allt Leachdach	6.47	2 375	828	33
Hodge Beck	18.9	1 057	294	216
Bottoms Beck	10.6	1 529	219	237
Croasdale Beck	10.4	1 839	367	99
Hodder	258	1 547	491	25 348
Burbage Brook	9.1	1 004	170	66
Severn	8.05	2 449	409	92
Wye	10.4	2 532	399	69
Kym	138	594	84	2 443
Honddu	62.2	1 193	331	2 995
Afon Honddu	24.6	1 405	441	391
Halse Water	87.8	909	373	843
East Dart	21.5	2 103	295	257
Fowey	36.8	1 518	231	559

methods have already been described for calculating the magnitudes and lengths of all links in a network and their topologic and geometric distances from the outlet (Ferguson, 1977). The size of channels in the drainage network is important in addition to the length and density of channels because two basins with networks identical in density could have different flood-producing potential if the channels were larger in one basin than the other. This feature of the drainage network has been identified by calculating an index of stream network volume based upon the relation between channel cross-sectional area (channel capacity) and total channel length (Gregory, 1977b). A further feature of the drainage network that requires consideration is the vertical dimension, namely, the relief of the network. A composite index which embraces density and size of channels as well as relief could be the basis for an index which has an easily recognized physical significance. The development of such an index can be thought of by exploring the analogy with a hydraulic approach.

AN INDEX OF NETWORK POWER

Recent progress in the study of river channels has been possible by the application of hydraulics concepts to river channels and Simons (1975) has shown, for example, how a variety of river channel changes can be approached from a hydraulic point of view. An important concept particularly useful in relation to sediment discharge was the concept of stream power as introduced by Bagnold (1960) and developed in later papers (Bagnold, 1966). Implicit in the concept was the expression of the available power of an open stream flowing down a constant slope $\Omega = \rho gQS$, where ρ is the density of fluid, g is the acceleration due to gravity, S is the energy slope, and Q is the discharge. Some workers have expressed stream power a little differently. Benson and Dalrymple (1967) expressed it as 62RSV, where 62 is the specific weight of water, R is the hydraulic radius, S is the water surface slope, and V is the mean velocity. However, the essence of stream power at a river channel cross section is that it is related to velocity, size of the channel and character of the fluid. Most recently, unit stream power, the time rate of potential energy expenditure per unit weight of water in an alluvial channel, has been used by Yang (1976) as the basis for a hypothesis of minimum unit stream power which describes the general tendency of an alluvial channel and which can be employed to understand adjustments of velocity, depth, slope or roughness of the alluvial channel.

Equivalent progress has not yet been achieved in the characterization of the potential energy of the drainage basin. Simons and Gessler (1971) have asserted that theory on hydraulic processes (relevant to the channel) is years ahead of theory on geomorphic processes (pertinent to the drainage basin). A method is required whereby potential power can be indicated from drainage basin characteristics so that the potential velocity of peak flow at a specific river reach can be estimated from the upstream characteristics of the basin. Over the last two decades a number of methods have been devised, often utilizing large numbers of basin characteristics, but smaller numbers of significant indices are required to give an index of network power. In Great Britain, the search for meaningful watershed parameters was intensified in the work associated with the Flood Studies Report (Natural Environment Research Council, 1975) which includes an explanation of those indices which are involved in the methods proposed for flood estimation at sites on rivers in Great Britain.

An index of potential drainage basin power is required for further progress to be made and this has been developed for a number of basins listed in the Flood Studies Report. The drainage network is fundamentally significant but density of the network alone ignores the size of stream channels, so that Gregory

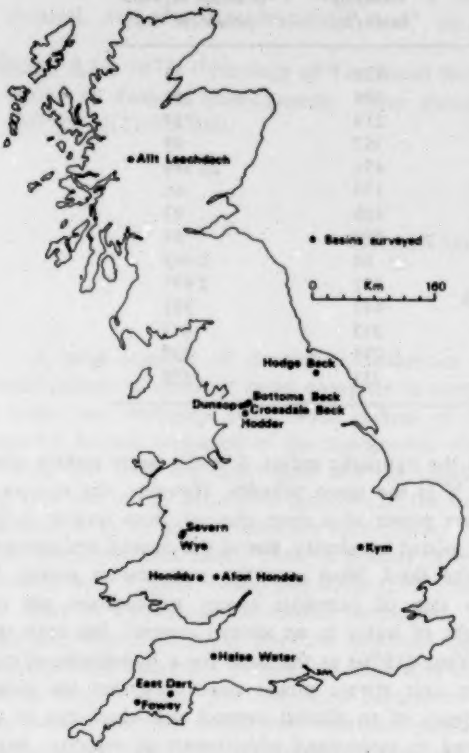

Figure 1. Locations of 14 basins in the United Kingdom where field surveys of channel capacity were made as basis for development of relation between capacity and total channel length

(1977b) developed a volumetric index from the relation between channel capacity and total stream length in a basin. This volumetric index has now been applied to 14 basins (figure 1) analysed for the Flood Studies Report. The basins were chosen with drainage areas up to 258 km^2 and in a range of locations (figure 1) with different precipitation characteristics and with contrasted flood-producing potential (see table). In each basin the drainage network was identified from the most recent 1:25,000 ordnance survey map and for some basins this network was checked from aerial photographs. At a number of sites throughout each basin the river channel cross-section was surveyed to the capacity level, and 369 cross sections were surveyed in the 14 basins. For each basin the relation between channel cross-sectional area or capacity C and total channel length ΣL above the surveyed section was established in the form $C = a\Sigma L^b$. Integration of this expression between network limits $\Sigma L = 0$ and ΣL to the gauging station gives an approximation for the total stream channel volume in the drainage area above the gauging station (Gregory, 1977b). Values of stream channel volume derived in this way are superior to density of stream channels because the size of stream channels is included as well as the spatial extent, and larger channel volumes would be expected to allow higher river velocities and so to induce higher flood discharges. However, volume of the drainage network is not effective alone because the roughness of the channels making up the network, the storage potential, the arrangement of the channels and the relief dimension should also be considered. Relief may be particularly important because when combined with channel volume, the resulting index can represent potential water velocity and hence provide an index of drainage network power. This was first calculated for each of the 14 basins as the product of the estimated channel volume in the basin (V in cubic metres) and the total relief of the basin (R in metres). However, a more convenient way of expressing the index is provided by V/R, which gives the volume of stream channel per unit height (see table). Large values of the index of drainage network power would be expected to give rise to the highest velocities and so to the greatest peak discharges.

The index of drainage network power was related to an index of peak flow from each basin (figure 2) expressed as the mean annual flood derived from the two peaks per year partial duration series (PT2 MAF)

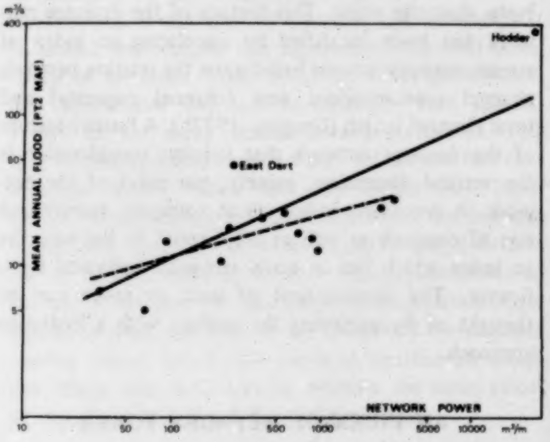

Figure 2. Relation between drainage network power (NP) and mean annual flood (PT2 MAF) for the 14 basins shown in figure 1 and detailed in table. The solid regression line is fitted to all points, and the dashed line is fitted to 12, excluding the East Dart and Hodder basins

as employed in the Flood Studies Report (Natural Environment Research Council, 1975). The relation between mean annual flood and drainage network power (NP) is shown in figure 2 and is expressed in $\text{PT2 MAF} = 1.3684\ \text{NP}^{0.456}$, where $r = 0.8254$ and 68 per cent of the variance is explained. This relation (figure 2) can be used as the basis for an indication of the magnitude of mean annual flood from a single composite catchment characteristic which reflects other characteristics and also is related to climatic variables.

CONCLUSIONS

An index of drainage network power is potentially useful in at least two ways. First, to assist progress towards improved modelling of hydrograph generation from a drainage basin. The most recent models are beginning to take account of contributing areas (Lee and Delleur, 1976) and of channel types (Thornes, 1977), but it is also necessary to incorporate channel size and character of the drainage network as a whole. Indeed, several authors (e.g. Thornes, 1977; Gregory, 1977a) have recently stressed the need for a better understanding of the relation between channel characteristics and the drainage network system as a whole. Second, it is necessary to have an integrated expression of the interrelation between stream channel size and stream channel extent as the basis for an estimation of temporal changes in fluvial systems.

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IS YOUR WEATHER BEING MODIFIED?

*Stanley A. Changnon, Jr.**

Public concern and scientific awareness of inadvertent weather modification have grown rapidly in the past 10 years. Urban-produced weather modification has been clearly recognized for many years, and the clouds and fogs induced by large power plants are obvious. All facets of the weather and climate, including the temperature, humidity, clouds, precipitation, wind, visibility and air composition, are changed by large cities. Weather changes are primarily caused by changes in the radiative and heat budgets of the atmosphere. The regional development of haze results from a combination of pollutant and radiative effects.

Inadvertent weather modification can occur over areas ranging from one up to thousands of square kilometres and can last from minutes to days. Differences between inadvertent weather modification and climate modification are subtle and hard to define. In general, inadvertent weather modification, as opposed to inadvertent climate changes, refers to shorter-term effects found to occur only during certain atmospheric conditions and occurring over smaller geographic scales.

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* Head of Atmospheric Sciences, Illinois State Water Survey, Urbana, Illinois, United States. The following text is extracted from the article of the same name, published as paper No. 15253 of the proceedings of the American Society of Civil Engineers, *Journal of the Irrigation and Drainage Division* (ISSN 0044-7978), vol. 106, No. IR1 (March 1980). Copyright, American Society of Civil Engineers, 1980.

A 1977 assessment of unintended weather modification appears in table 1. This reflects the current scientific certainty of unintended weather changes sorted by the scale of the weather change. Examination shows that most unintended modifications are mesoscale (extending less than 150 km) and most of what is known with certainty is associated with urban areas. For each class, the general significance of the impacts on the climate and man is indicated.

This paper reviews how land-use changes alter the atmosphere, and then it describes the types of weather changes produced by cities, isolated production centres, rural lands and transportation corridors. Knowledge of the types of weather and climate changes, their importance and their causes should be valuable to those concerned with the design and operation of urban-industrial facilities and of agricultural and transportation systems.

PROCESSES OF MODIFICATION

Most inadvertent precipitation modification begins with alteration of the surface climate. The temperatures over plowed fields are much higher than they were under the previous forest canopy. The humidity over irrigated farmland is much higher than it was over the arid grassland that previously existed. A city's presence causes higher temperatures and lower winds.

Most of man's unintentional modification of weather has come from changes in the distribution of energy, e.g. we have agricultural fields in lieu of natural fields and artificial lakes instead of arid valleys. Most recognized distribution changes occur as a result of changes in surface colour, surface texture (which changes thermal and evaporative properties), surface topography, and the release of particulates. Certain gases, such as SO_2, released in the atmosphere become particulates or, specifically, sulfate compounds, and once formed over a large area become haze. Widespread haze affects the albedo and thus the heat budget and weather. (Large-scale changes in atmospheric gases, such as CO_2 and ozone, will also alter the temperature distribution because of their absorption properties. However, in these cases the form of atmospheric modification will be more in the "climate" than in the "weather" range.)

In addition to these man-made distributional changes in energy, the total energy released by use of fossil fuels has resulted in a significant additional amount of energy that must be disposed of through radiation to space. Such a change in outgoing radiation produces sensible heat changes and affects cloud growth.

Changes in the atmosphere's moisture content, usually through increases in humidity by industrial processes, irrigation or large man-made lakes, combine to produce more clouds under some conditions. This in turn affects the energy budget (lowers temperature), can change precipitation and could eventually reduce cloud cover through reduced convection. Changed roughness of the land surface, such as the erection of a major city in flat country or removal of a large forest, affects the airflow mechanically – which in turn alters wind speed and direction.

Table 1. Effects of man's unintended weather modification

Weather phenomenon (1)	Scale of modification* (2)	Certainty of unintended modification (3)	Importance or significance of weather effect (4)
Visibility and haze	meso	certain	major
	macro	possible	moderate
Radiation budget and sunshine	meso	certain	moderate
Cloudiness	urban	certain	moderate
	meso	probable	moderate
Precipitation	urban	certain	major
	meso or macro	possible	moderate
Thunderstorms	urban	certain	major
(hail, heavy rains)	meso	possible	major
Severe storms (tornadoes, other)	unknown	unknown	unknown
Temperature	urban	certain	moderate
	populated meso	possible	minor
Wind/circulation	urban	certain	moderate
	meso	unlikely	unknown
Fog	urban/micro	certain	major
Humidity	urban/micro	certain	moderate
	meso	certain	moderate

*Micro = ≤1 km; urban = ≤30 km; meso = 30 km–150 km; macro = ≥150 km.

URBAN AREAS

The urbanization that began in the eighteenth century A.D. has led to relatively significant local and mesoscale changes in the weather in and near cities. Since sizeable cities first proliferated in Europe, the realization of their weather effects first appeared there too.

Cities are great converters of energy and matter, and their products directly affect the heat and moisture budgets and the exchange of materials in the atmosphere. Consequently, the changes in weather wrought by urbanization encompass all major surface weather conditions. The degree of change in any weather element at any given time depends upon the areal extent of the urban-industrial complex, its types of industry, its juxtaposition to major water bodies and topographic features, time of day, season of the year, existing weather conditions and regional climate. Urban areas often act as mechanical barriers to airflow, even retarding the forward motion of fronts. Typical temporal differences produced by cities can be shown by urban solar radiation, which is decreased by cities: (a) much more in the winter than in summer; (b) more on weekdays than on weekends; and (c) more in the morning than in the afternoon.

The degree of change in several weather elements, produced by urbanization, is summarized in table 2. The change is expressed as a percentage of rural values, e.g. urban versus rural temperature differences resulting largely from the heating of urban structures are much greater in winter than in summer. However, urban temperatures during certain seasons and weather conditions can be higher or lower than nearby rural temperatures; opposite types of changges in certain weather conditions occur at different times.

The effects of urban areas on weather and microclimate that are easy to measure include decreased visibility, reduced winds, changed humidity and increased temperature. However, the visibility within a city varies considerably as particulates released from varying land uses (commercial, industrial, residential) vary considerably.

The temperature within a moderate (100,000 population) to large-size urban area is generally higher at any given time of the day or season than it is in rural areas because the most radical change produced by cities is in the heat balance. The temperature effect has been well recognized and quite well measured in many cities for many years because its surface measurement is easy. Recent measurements have shown that the daytime urban heat excess often extends vertically 2000 metres or more up, and a thermal and pollutant plume often extends many kilometres downwind. Urban areas often act to decrease winds and alter their direction near the surface, to increase turbulence and vertical motions in their immediate areas, and to create localized rural-urban circulation patterns at the surface.

Humidities over cities in humid climates are generally decreased because much of the rain runs off and there is less plant area to provide moisture to the atmosphere. But cities with extensive industries involving large volumes of cooling water, such as the petroleum industry, may have a net increase in humidity, at least in a local area. Excessive irrigation of lawns in semi-arid cities will also increase humidity.

Hard-to-measure weather changes caused by urban areas include shifts in fogginess, cloudiness, precipitation, snowfall, solar radiation, atmospheric electricity and servere weather.

Table 2. Weather changes resulting from major urbanization in the northern hemisphere, as a percentage

Weather phenomenon *(1)*	*Average changes compared to rural conditions* *Annual* *(2)*	*Cold season* *(3)*	*Warm season* *(4)*
Contaminant volume	+1,000	+2,000	+500
Solar radiation	–22	–34	–20
Temperature (Celsius)	+2	+3	+1
Relative humidity	–6	–2	–8
Visibility frequency	–26	–34	–17
Fog frequency	+60	+100	+30
Wind speed	–25	–20	–30
Cloudiness frequency	+8	+5	+10
Rainfall	+14	+13	+15
Snowfall	±10	±10	–
Thunderstorm frequency	+15	+5	+30

Concern over the complex problem of urban effects on clouds, precipitation, and related severe weather recently led to major climatic and field investigations.

Causative explorations have been employed in a few field studies of power plant sites and in one major urban study of St. Louis, Missouri. This extensive seven-year effort (1971 to 1977) is known as METROMEX (Metropolitan Meteorological Experiment); it was the United States of America's first sizeable field study of unintended weather modification. Other studies of unintended modification have relied on use of computer models of clouds and airflow that can simulate the various man-made changes in the heat and moisture budgets, in particulates and in surface roughness.

METROMEX

The major urban rainfall investigation has been METROMEX, the world's first large field and modelling programme to establish clearly where and how an urban area affects clouds and precipitation. The field programme as St. Louis produced results that discerned and largely explained the summer rainfall increase (figure 1).

St. Louis, through alterations of the local temperatures, moisture, and wind fields, plus contributions of additional nuclei from aerosols, acts to trigger or enhance warm-season cloud and rainfall activity. This often occurs in urban-produced convergence zones in the low-level wind field, and the place of cloud activity and ensuing rainfall depends on surface conditions, wind direction on any given day, and the degree of atmospheric instability.

More urban clouds and rain elements on some days interact to enhance rainfall and local storminess. The METROMEX findings revealed local increases of 30 per cent in total rainfall, 40 per cent in heavy rainfall rates and storms, 45 per cent in thunderstorms, 100 per cent in strong surface winds, and 100 per cent in hailfall intensities.

Cities are sources of cloud condensation nuclei (CCN) and can produce or destroy ice nuclei; these nuclei are part of the unintended modification. The presence of the nuclei added by cities and scattered industrial and power plants between cities will affect attempts at purposeful weather modification. Regional weather changes far downwind of cities may result as the man-generated aerosols CCN and ice-forming nuclei (IFN) produce haze and affect the microstructure of clouds and precipitation.

RURAL NON-AGRICULTURAL LANDS

Rural non-agricultural lands include a variety of surfaces that collectively encompass a large portion of terrestrial earth: forests, swamps and grasslands. All non-agricultural lands contain a high density of plants and trees, which form a crucial link in the earth's ecosystem since they capture and release energy, moisture and gases. Thus, substantial changes in the cover of green plants will lead to microclimate changes, then weather changes, and eventually to larger-scale climate change.

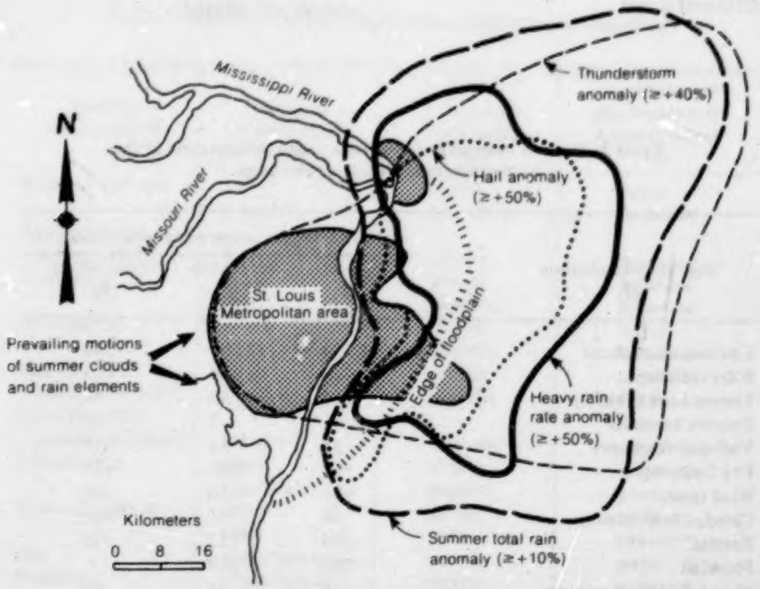
Mississippi River
N
Missouri River
Thunderstorm anomaly (≥ +40%)
Hail anomaly (≥ +50%)
St Louis Metropolitan area
Prevailing motions of summer clouds and rain elements
Edge of floodplain
Heavy rain rate anomaly (≥ +50%)
Kilometers
0 8 16
Summer total rain anomaly (≥ +10%)

Figure 1 Anomalies discerned in summer precipitation conditions in the St. Louis area

Deforestation leads to an increase in solar radiation received at the surface, the single greatest atmospheric change produced. The solar radiation received in a cleared area may be up to 150 times greater than that received at the ground in a forested area. This great change in incoming radiation causes great differences in surface temperature and other low-level weather conditions. Such changes have been suspected to lead partially to increasing frequency of drought and a general drying of the climate in eastern Europe. Extensive deforestation in the tropical and subtropical climates of Latin America is suspected to cause more regional extremes of climate, including wider variations in temperatures and, in turn, more severe droughts and more heavy rains. Midlatitude areas of the northern hemisphere have had their microclimates markedly changed by deforestation, but the relative slowness of the deforestation helped mask any ensuing changes in weather (clouds and rainfall). In general, it appears that total rainfall could be reduced between 1 and 10 per cent, depending on climate and forest type, by the extent of forest change.

Alteration of natural grass lands has largely involved changes to cultivation or to pasture land. Resulting atmospheric changes by shifting to field crops are minor and are largely microclimatic. However, shifts of grass lands to overgrazed pasture land, particularly in semi-arid climatic zones, have been claimed to produce weather and climatic changes. Extensive areas of the Middle East and Far East have undergone such man-made alterations in their grass ecosystems. The overgrazing in northern India for centuries apparently resulted in enormous additions of dust to the atmosphere that, through sizeable alterations in radiation, could have helped produce the extensive Rajasthan Desert, a region of 1.3 million km^2. Sizeable amounts of atmospheric dust come from the cultivation of natural grass lands in Asia. The impact on climate of the "brown haze", made partially by man in various parts of the world, has been suggested to be even greater than the effects attributed to CO_2 and combustion particulates; this is still debated among the experts. Man's drainage of bogs and swamps to develop land for cultivation or urban building often has profound microclimatic effects, but these land alterations have not been noted to have appreciable effects on weather.

Large-scale strip mining, which will remove ground cover, change the topography and surface colour, and add dust particles to the air, will likely modify the microclimate with possible influences on some weather conditions. Obviously, wind speeds and temperatures will be increased, and humidity and visibility will be decreased. However, no measurements have been made, and effects on clouds and rainfall can only be guessed at. Restoring ground cover to mining sites would help make sure that unwanted weather effects are not a permanent local condition.

AGRICULTURAL LANDS

Agricultural lands affect local microclimate, but weather changes resulting from man-made changes in crops or pasture are likely minor. The primary biospheric changes by man through agricultural activities concern technological practices, some of which might conceivably have profound effects on weather. Most such weather alterations are not well established.

Surface heat differentials that could affect the weather exist in many areas as a result of seasonal and spatial differences in crop types and in the arrays of crop and bare soil in dryland farming. Their effect is as yet unknown.

The "slash and burn" approach to the elimination of crop and weed residues has been practised for centuries in certain humid tropical zones of the world with two to three crops per year, such as in south-east Asia. In the midlatitude agricultural areas, burning of plant debris is still a widely used method of residue elimination, and in the United States it is a source of atmospheric pollution. The widespread burning of organic material inserts vast quantities of particulates into the atmosphere that can readily affect radiation and visibility. Some may be effective as CCN and affect cloud and rain production. Rainfall studies in Arizona suggest that aerosols from burning of weeds and tree prunings also affect raindrop sizes, rain rates and the total rainfall. The burnoff of sugarcane in Hawaii has long been noticed as a man-made producer of thicker, longer lasting cloud cover, but the trade winds make the condition temporary. Fires of sugarcane residue in Australia produce sufficient condensation nuclei to inhibit rainfall, possibly resulting in a 25 per cent decrease over a large area.

Irrigation is normally practised either by letting the water flow through fields or by some form of overcrop sprinkling. Both approaches, if practised over a wide area, result in the sizeable addition of moisture to the low-level atmosphere with resulting higher humidities, lower albedo and much lower daytime temperatures, all of which can alter the wind circulation. Effects on microclimate from widespread irrigation appear to be realized in the cloud and rainfall processes, particularly in subhumid regions. Intensive irrigation is thought to have produced a rain increase of 25 per cent over more than 1,000 km^2 in the Columbia Basin in Washington. Studies of the historical weather data for the enormous (47,000 km^2) irrigated area of the Great Plains, from Texas to Nebraska, suggest summer season rainfall increases of 15 to 50 per cent, depending on the location and the year's weather conditions. The area of altered rainfall appears to be 260,000 km^2. Studies of physical causation are yet to be pursued.

TRANSPORTATION CORRIDORS

The release of large amounts of water vapor in the exhaust of aircraft flying in the upper troposphere or lower stratosphere results in the commonly observed "contrails". On some occasions, when the conditions at flight levels are favourable (near water saturation and above ice saturation), the contrails persist for hours, spreading and merging to produce, over heavily traveled routes, extensive shields of cirrus clouds. Such shields reduce incoming solar radiation and lower surface temperatures, and the ice crystals falling from such shields may act as freezing nuclei in lower cloud decks and affect the amount of precipitation produced. Such weather effects are currently speculative and need study. Although effects are physically plausible, their magnitude is unknown, and could be important or insignificant.

Major surface transportation corridors affect the atmosphere by the direct heat emissions from vehicle exhaust, by the re-radiation of solar radiation absorbed by the road surface, by moisture emissions and by pollutants from vehicles. These lead to local temperature changes and can lead to fog formation or aggravation of existing fogs. The wind profile over freeways is changed and additional turbulence induced. Such corridors also add to regional concentrations of particulates that diminish visibility and potentially affect clouds.

SUMMARY

Atmospheric scientists generally agree that the magnitude and areal extent of inadvertent weather modification are growing in the United States. They also agree that studies of the subject can be best served by a broad comprehensive programme. The future research needs relate to weather changes on the local or microscale, the urban scale and the regional scale.

Most of what is known about inadvertent weather modification rests on statistically focused studies. What is now needed – more complex studies of causation – is still ahead of us in most of the categories of land-use change. An overriding recommendation relating to future research in inadvertent weather modification is the need to gain a greater understanding of a phenomenon that is as yet largely ill-defined.

Inadvertent weather modification has pervasive, interdependent effects. It has been discerned to result from five general types of land use, or biospheric, change: urban areas, major production centres, shifts in rural non-agricultural land use, activities on agricultural lands and transportation corridors. Such weather modification can ultimately blend into modification of climate.

Urban influences on weather have been more thoroughly studied than any other facet of inadvertent weather modification. The influences are sizeable and pervasive in the local area. The sizeable impacts of urbanization make further study and identification of this particular phenomenon a top-priority area.

Alterations of rural areas have led to some weather alterations in clouds, rainfall and storms. The rural land-use changes have produced weather and climate alterations that generally have occurred more slowly and subtly than urban changes, which are more discernible than most others because they are more concentrated. The urban source region is obvious, the potential effect region can be delineated within reasonable bounds.

The many major urban centres plus the high density of power plants, traffic corridors and industrial centres in rural portions of the north-eastern quarter of the United States suggest that some weather forms, and clouds in particular, are being unintentionally modified in much of that large and congested region. Unintentional modification due to irrigation, power plants and large cities elsewhere in the nation is likely sizeable in some areas. Many of these changes in weather have a direct impact on efforts to modify the weather on purpose.

An overriding scientific question with respect to the rural changes and the urban-related weather changes is whether they separately or in conjunction may reach critical levels and become "triggers" that would result in much larger regional weather and climate changes. Existing theory and atmospheric models cannot yet interpret nor predict such possibilities.

RESEARCH NEEDS: HYDRAULICS, COASTAL ENGINEERING AND IRRIGATION*

In 1979, the American Society of Civil Engineers and the National Science Foundation held a workshop on research needs in civil engineering. The workshop report on the subcategory of hydraulics/coastal/irrigation engineering contained the following research priorities.

AGGRADATION/DEGRADATION OF BED AND BANKS OF ALLUVIAL RIVERS

Alluvial streams are authors of their own geometry. They wander by eroding the outsides of river bends and depositing material on the insides, and change bed depth by depositing alluvium in some locations and scouring it from others.

For example, bank erosion is destroying several acres of agricultural land per mile per year along the Sacramento River. Bed degradation of the Missouri River, amounting to about eight feet in the vicinity of Sioux City, is seriously threatening water intakes, bridge piers, shore structure etc., and is effectively draining many ox-bow lakes in the valley. Shoaling (deposition of sediment) among some reaches of the Mississppi River requires dredging amounting to upwards of 100,000 cubic yards per mile in some areas. Problems such as these characterize practically every major river in the country.

Unfortunately, the details of the processes involved in scour and deposition are so poorly understood that new, more economical means of controlling them have not been forthcoming.

EROSION SAFETY OF EMBANKMENT DAMS

Many government regulations require that embankments be analysed for failure due to overtopping. At present such evaluations are based primarily on the sketchy data obtained from the few embankment failures that have been reported. More and better data are needed before really meaningful evaluations can be developed.

The evaluation of dam failure for safety of nuclear power plants or under the United States National Dam Safety Act is fraught with uncertainties because of the absence of a known rate at which engineered structure fail. This research would be conceived to establish correlations between quantity of water, velocity of water, grain particle size and rate of erosion.

Research has been conducted at many foreign and domestic laboratories. Existing knowledge needs to be combined with additional research to establish criteria immediately useful to designers. This probably means field construction of typical sections with test to failure. It will take a carefully conceived plan, but should result in analyses that will ensure safety to all those living below man-made embankments without unduly penalizing the proposed structure or exaggerating the possible flooded areas due to use of ultraconservative input criteria because of the present uncertainties.

DESIGN CRITERIA FOR HIGH-VELOCITY FLOWS

Recent design efforts for very high head projects, designed by American engineers for many parts of the world, have led to the realization that satisfactory design criteria are not available to accommodate the high-velocity flows that develop in such projects.

For example, the limiting velocity for a particular concrete mix (that is, the velocity beyond which scour and/or cavitation damage may become serious) is not known nor is it known if mixes can be developed for some of the higher velocities encountered.

In addition, surface irregularity tolerance criteria are needed. These are all critical items affecting the ultimate safety of the projects. Moreover, while model testing will almost certainly be required, better preliminary design criteria for the channel bends, contractions and expansions and for expected forces are needed to reduce both design time and cost.

Until better design criteria are developed, the potential exists for future serious problems, such as at Tarbela Dam in Pakistan.

RISK ANALYSIS FOR DESIGN OF HYDRAULIC STRUCTURES

Design of hydraulic structures, such as energy dissipators, is often based on conditions with very infrequent recurrence, and without consideration of the actual risks of designing at some lower level.

Large expenditures are being made for revision of dams and associated structures without benefit of risk analysis.

[Editor's note: Public concern about dam safety, for example, has led to requirements that dams and appurtenances be designed for storms with extremely long return periods. No doubt this makes them safer. But such extreme design requirements raises the question of whether this represents optimal expenditure of public funds. If public monies were unlimited, the answer would be yes. But they are not. Such requirements are predicated on a belief that the public will tolerate virtually zero risk to human life. Yet each year the American public manages to drive motor vehicles in such a way as to kill more than 50,000 people. The number killed in dam failures is tiny. (One important qualifier: Analysis of perceptions of risk shows people will accept a risk 10 times as great if they voluntarily accept it, as opposed to involuntary risk. An example of the former is driving a car, and of the latter, buying a house below a dam when unaware of the statistical possibility of dam failure.)

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* Extracted from the article of the same title published in *Civil Engineering - ASCE* (ISSN 0360-0556), vol. 52, No. 4 (April 1980), pp. 83-86. Copyright, American Society of Civil Engineers, 1979.

Of course the agencies responsible for carrying out dam safety laws, such as the United States Corps of Engineers, cannot act other than as the law and their interpretation of it dictate. The problem is more one of public edducation than of engineering. But a case can be made that engineers will be acting in the public interest if they optimize the spending of public money by not designing for zero risk.]

IMPACT OF SEDIMENTS IN WASTE PLUMES ON WATER-BOTTOM LIFE

Many waste outfalls contain settleable solids or suspended solids which, when mixed with the ambient receiving waters, coagulate and form a settleable floc. This is particularly true of wastes discharged into salt weter. Sediment accumulation at outfalls affects the benthic (sea bottom) community and indirectly affects higher life forms that graze on the benthos.

The depth and aerial extent of this sea-bottom sludge accumulation determine its seriousness. Such determinations must be made as part of environmental impact assessments of proposed outfalls and as part of the United States Environmental Protection Agency (EPA) regulations for waiver of secondary treatment requirements for coastal discharges. But we do not yet have the analytical tools to estimate the magnitude and extent of sediment accumulations.

Until these tools are developed and their reliability demonstrated, environmental impact statements and waiver applications will be hopelessly entangled in a word battle of speculation between the dischargers and the regulatory agencies.

Millions of dollars of design and construction monies for waste outfalls are being held up because accurate assessments of the impact of the sediment blanket on the benthos cannot be made. There is also the real possibility that secondary treatment facilities may be built that otherwise might have been waived, had accurate estimates of sediment accumulation been available.

PHYSICAL MODELLING OF CONCRETE SHORE-PROTECTION UNITS

Today's approach to design and modelling of protective armor schemes considers the individual weight, specific weight and geometry of the prototype armor. Structural characteristics of the units are not simulated.

There is a critical need for additional design guidance on the structural abuse that individual concrete armor units can experience before breaking. This belief is strengthened by recent instances of breakwater damage that may be partially due to broken armor units, such as at Sines, Portugal.

This gap in design knowledge can most effectively be filled by improvements in physical-scale modelling.

Potential benefits of such knowledge include more efficient and economical designs, lower maintenance cost, safer structures and the ability to reliably predict dollar trade-offs between initial cost and expected maintenance.

Why bother with such research? Absence of the needed knowledge could make designers reluctant to consider new concepts, or could result in extravagant over-designs. Either could result in the elimination of otherwise viable projects because of unnecessarily high cost.

IN IRRIGATION AREAS, WATER USE BY ENERGY PROJECTS

Such coal-rich western American states as Wyoming and Montana are also short of water.

Many western farmers fear that proposed huge energy projects (power plants, synfuel facilities, coal slurry pipelines) would use quite a bit of water, robbing farmers of their irrigation water.

Is there any way the two types of activity (for instance, irrigated farming and a central station power plant) could coexist and in fact help each other?

There may indeed be, predicts civil engineer Don Harleman. Suppose a big reservoir were to be built with both uses in mind. Might cost-justifying of its construction be easier with joint use? After all, the power plant does not use up the water; it merely uses a lake to cool water after it has passed through the plant.

The western water "problem" may be as much emotional and political as anything. If the two factions, energy developers and irrigation farmers, could sit down in an environment of co-operation rather than confrontation, perhaps in many locations both groups could get what they want.

IRRIGATION IN HUMID AREAS

Humid-area irrigation has been touted as an important source of additional crop output. If this is to be accomplished, less costly irrigation systems are needed.

Today's systems were designed primarily for arid regions. The technology is not directly applicable to humid areas, where lower-cost systems are required.

IRRIGATION ENERGY EFFICIENCY

Today's irrigation systems were designed in a time of cheap energy. But energy costs are skyrocketing, forcing the operation of irrigation systems in such a way as to yield poor water-use efficiency. Needed are new approaches to design new systems, and ways to retrofit existing systems that reduce the use of energy.

Water Resourcefulness Department

1980 ABC Inventor of the Year

Mr. M. Riha of Groundwater Section, Geological Survey of Victoria won the 1980 ABC Inventor of the Year award for his water sampling device. Subsequently, he won three awards for that invention at the Ninth International Exhibition of Inventions held in Geneva from 29 November to 7 December 1980. These awards were:

- one of the world's 1,000 most important inventions;
- a gold medal with special commendation from the jury panel in the category of environmental inventions;
- the 1979-1980 World Health Organization prize for the most appropriate health-related device.

Mr. Riha's water sampling device is a device for installing in pollution observation bores to allow sampling of the groundwater without it being contaminated by the sampling device. He was assisted in its development by a small grant from the Water Research Foundation.

-- From *Water Resources Newsletter* (Australia), 1981

Putting a pest to good use

Water hyacinths will be used in cleaning up chemical wastes from the Exxon Company's refining and petrochemicals complex in Baytown, Texas, USA. The aquatic plants will be planted on 25 acres of ponds after five years of Exxon tests in 1,000-litre tanks and four one-quarter-acre research ponds proved effective on effluent from the facility. The water hyacinths utilize the chemicals in the waste as nutrients and encourage the proliferation of waste-feeding bacteria, but discourage algal growth.

The hyacinths will be used for final cleanup of the 20 million gallons per day of effluent discharged from the Exxon plant. The waste entering the hyacinth-filled stabilization ponds will have undergone in-plant treatment, oil-water separation and aeration. The ponds are expected to reduce total suspended solids, mostly algae and, as in the test ponds, improve over-all water quality by lowering biochemical oxygen demand (BOD) and the levels of phenols and other chemicals.

Water hyacinths might enable industry to meet stricter effluent standards proposed by the US Environmental Protection Agency (EPA) for 1 July 1984, according to Gilbert V. Chambers, senior research associate with Exxon Research and Engineering Company. The EPA proposal would require best conventional technology for treatment of total dissolved solids, biochemical oxygen demand, fecal coliform bacteria, pH, and oil and grease, and stringent best available technology for treatment of toxic pollutants. Use of the plants would eliminate the need for energy-intensive methods, such as mechanical filters.

Aside from treating the effluent, the hyacinths also provide an improved wildlife habitat, Chambers noted, and are popular with wild-life. Environmental benefits of the hyacinth treatment method was also noted by Seabrook Seafoods of Kemah, Texas, which has been testing the plants for the past year on waste water from its shrimp-processing plant. Noticeable increases in fish populations have resulted in the area where hyacinth-treated water enters a nearby bayou.

Water hyacinths are rampant growers and in tropical areas of the world they frequently clog major waterways. The hyacinth-treatment technique, developed by researchers of the US National Aeronautics and Space Administration (NASA), involves careful containment of the plants and controlled harvesting. The harvested plants offer potential uses such as fertilizer, protein, and as a mineral additive to cattle feed.

-- From *Water Newsletter* (USA), 15 May 1981

TECHNICAL APPLICATIONS

WELL DISINFECTION...HOW FAST? HOW SURE?

*Elmer E. Jones, Jr.**

Well disinfection is a problem for almost every water-well contractor. Many drillers do not fully understand the way disinfectants work, how chlorine demand varies throughout the well and the difficulties in achieving proper disinfectant distribution. It is also rare that drillers understand exactly how the time that elapses between disinfection and well-testing affects the test results.

Some form of chlorine is the substance most often used in disinfection, so it is important that drillers understand how it reacts in water. Reaction with reducing ions such as ferrous and manganous ions, nitrite, sulfide and sulfite form the initial demand (see figure 1). The chlorine reduced to chlorides in these reactions has no disinfection ability. Additional chlorine will then react with ammonia and certain organic compounds to form chloro-organic compounds and chloramines. Combined residuals reach a peak (point C), then decline as more chlorine is added, offering a limited disinfection ability. The point at which combined chlorine residuals reach a minimum and a free chlorine residual begins to appear is known as the breakpoint. Up to this point chlorine demand (dosage minus residual) varies with dosage. Beyond the breakpoint the free chlorine residual increases directly with dosage as free chlorine is a rapid disinfectant.

Much of the available chlorine lost to long-term chlorine demand is used to oxidize organic matter. The hydrochloric acid rapidly reacts with adjacent organic or mineral matter and normally increases the possibility of further chemical reaction.

The major chlorine demand of concern in well disinfection is not in the water, but on the surfaces of the well. Nuisance organisms (organisms able to reproduce in the environment of the well) often produce large quantities of organic matter. The result is a high chlorine demand and sufficient organic energy for the possible propagation of coliform if the water temperature is above 13°C. In addition, the submersible pump motor may be several degrees warmer than the well water and can create a micro-environment where coliform can reproduce in wells with water cooler than 13°C. Grass and weed stems on the riser pipe and electrical wires above the water level may also provide a habitat for nuisance organisms.

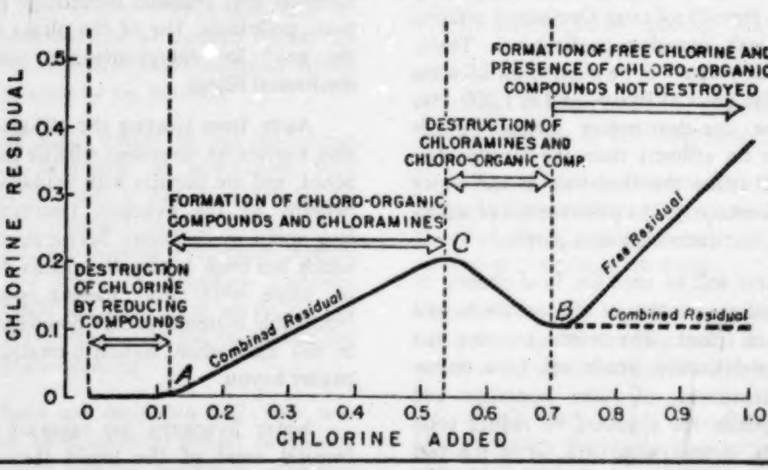

Figure 1. A chlorine demand curve for a water sample showing the initial demand, combined chlorine compound increase, peak and decline to the breakpoint where a free chlorine residual is first detected

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* Research Agricultural Engineer for Rural Sanitation, United States Department of Agriculture, Beltsville, Maryland, United States. Article originally published in *Water Well Journal*, vol. 33, No. 11 (November 1979) pp. 56-59. Reprinted with permission from Water Well Journal Publishing Company; copyright 1979. World-wide rights reserved.

Many nuisance organisms are filamentous or slime formers and produce particles that settle at the bottom of the well, along with soil particles. Until further evidence is available, it is wise to assume that 20 per cent of the chlorine demand exists at the bottom of the well. In wells that have been inadequately disinfected several times, over 90 per cent of the demand may be at the bottom due to settled slimes loosened in previous disinfection attempts.

Two chlorine products are commonly used in well disinfection, 5.25 per cent sodium hypochlorite (laundry bleach containing 50,000 ppm available chlorine) and 65 or 70 per cent calcium hypochlorite, available as a dry granular powder or tablets containing 650 to 700,000 ppm available chlorine.

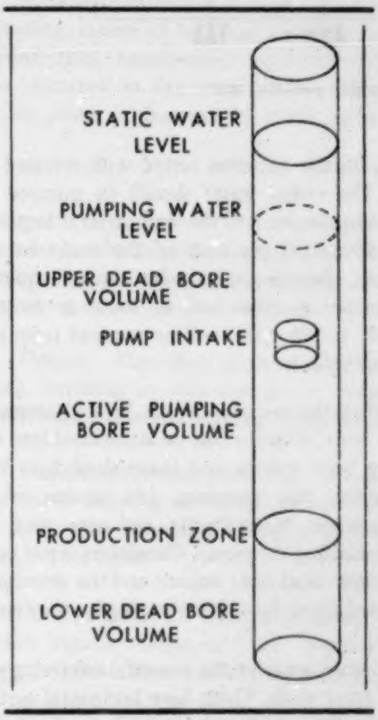

Figure 2. **Terminology applied to the well bore water volume in well disinfection**

Disinfectants are pesticides regulated by the United States Environmental Protection Agency in accordance with the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA). Every pesticide container must bear a registration and establishment number and be labeled in accordance with FIFRA Regulations. Products such as the hypochlorites have many uses and may have supplemental use instructions distributed in bulletins. The user should have the appropriate instructions present to be sure of compliance.

Laundry bleach poured into a well will stratify in the upper well water. Granular calcium hypochlorite settles too slowly and dissolves too fast to achieve uniform distribution. Calcium hypochlorite tablets have the opposite problem, initially settling at about 1.33 ft/sec and dissolving at about 3 per cent per minute.

Recently the United States Department of Agriculture provided information on settling and dissolving rates. They indicated that about 50 per cent of the granular calcium hypochlorite dissolves in the upper eight feet of the well. Other studies indicated that residuals would be lower at lower depths for tablets. After the initial rapid weight loss, the rate of weight loss was fairly constant: 1 per cent minute per square centimetre per gram. The series of studies also proved that a properly selected variety of particle sizes is required to give uniform dosage throughout a well bore.

Field use of the prefractured tablets is extremely fast and easy. The only other process that can produce a uniform dosage throughout the well is the installation of a tube at the bottom of the well through which the chlorine solution is discharged. The tube is gradually withdrawn as the chlorine solution is added, exposing all parts of the well. Use of prefractured tablets saves over two hours per well.

There is one serious problem: calcium hypochlorite manufacturers do not recommend fracturing tablets under field conditions since there is a danger of severe chemical burns, fire or explosion if adequate safety precautions are not taken (see box). The use of this technique by drillers will depend upon commercial firms making fractured tablets available. A removable stick-on label which could be dated and attached to the well casing would be desirable.

Chlorine residuals in well bores should be checked occasionally with one of the many available sampling devices. You can easily fabricate your own fitting 3/4 or 1-inch pipe length, 200 to 300 cubic centimetres in volume, with a check valve at the bottom and reducing coupling at the top. The lower portion of the check valve is cut off to minimize dead water volume below it. An air line is attached to the reducing coupling. The cylinder and air line are pressurized to hold the check valve closed until the desired depth is reached. As the pressure reduces, the cylinder fills with water and can be withdrawn. (A safety line may be attached to the reducing coupling. The cylinder and air line are pressurized to hold the check valve closed until the desired depth is reached. As the pressure reduces, the cylinder fills with water and can be withdrawn. (A safety line may be attached to the cylinder.) If the cylinder is lowered to the bottom of the well, bottom sediments may be obtained in addition to a water sample that may be checked for chlorine residual.

Unfortunately, little data has previously been published on well disinfection. However, when the most frequently heard complaint is "I can't clear it up, it's in the formation", current recommendations for displace-

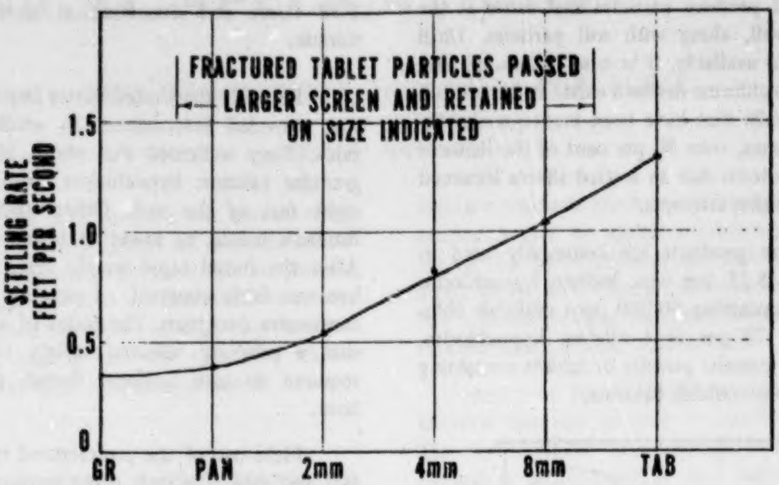

Figure 3. Settling velocities of tablets, tablet particles and granular calcium hypochlorite

ment disinfection should be reconsidered. A common recommendation is to back-flush the bore with two bore volumes of water containing 50 ppm of available chlorine. Water in the bore is forced back into the formation and is then followed by the chlorine solution. If the chlorine demand is high, slime sludge and chloro-organic compounds may also enter the production zone. Depending on the location and nature of the production zone, much of the bore may not receive any chlorine solution. A good rule to follow is not to force water from the bore into the formation until the bore is fairly clean and the displaced water contains a desirable free chlorine resitual. This can only be done after the installation of a pump.

My recommendations are as follow: place a strong chlorine solution in the well before installing the pump; the pump, pipe and wiring will then pass through this chlorine solution on entering the well water. Immediately after the pump is installed, the well should be pumped to waste over the upper casing terminal, not into the distribution system. After the pumped water clears, it may be returned to the bore and a chlorine compound added either to the return stream or directly to the bore. The returned water establishes a recirculating bore volume from the water level to the intake up the riser, to the upper casing terminal to be returned to the bore, or run to waste. When recirculating 100 per cent of the pumped water, it is possible to calculate the chlorine demand. For accuracy it is necessary to know the recirculating bore volume and pumping rate. A high-chlorine residual test kit is essential. Most are based on the iodometric method in standard methods, modified for easy field use.

Problem wells can have very high chlorine demands. When 500 ppm goes in and 50 ppm comes back after one recirculation cycle, you may wish to increase the dosage by 200 ppm. When this happens, the pumped water normally becomes turbid with released bacterial slimes. The turbid water should be pumped to waste rather than returned to the well. After it begins to clear, return 30 to 50 per cent of the water to the bore. Otherwise, clear water may be obtained quickly from the production zone but as soon as circulation is restarted, turbid water will be pumped from the upper dead bore volume.

When the pump intake is located above the production zone, chlorine can be introduced into the active pumping bore volume and lower dead bore volume in this manner: stop pumping, add batches of fractured tablet calcium hypochlorite and give time to settle before restarting the pump. Circulation is not established in the lower dead bore volume and the chlorine is rapidly removed from the active pumping bore volume.

In some areas of the country, centering guides are used in most wells. These have horizontal surfaces that will retain slimes and tablet particles and greatly reduce the chlorine that reaches the lower dead bore volume.

In areas where nuisance organisms are common or in wells where a very low standard plate count is desired, a means of establishing circulation from the bottom of the well to the pump intake should be provided. This can be 1/2 or 3/4-inch pipe, with a hose fitting a few inches below the upper casing terminal. The lower two inches should be perforated to discharge water in several directions and permit free discharge of water without pipe vibration. Calculation of chlorine demand is simplified if 100 per cent of the pumped water is recirculated. This also reduces chlorine requirements, as none is pumped to waste except when it is desired to waste turbid water. If not all water is recirculated, it is necessary to know the ratio of recirculated water to pumped water to calculate chlorine demand.

Without recirculation it is impossible to be sure that the chlorine demand of the lower dead bore volume has been satisfied. It also is impossible to remove the residual of bacterial slimes that have been killed and loosened by the chlorine.

The importance of understanding good well disinfection processes is illustrated by one conscientious well driller from whom we learned of this need. His standard procedure was to pour two gallons of laundry bleach into the well. If the health department found the well contaminated he would return, pour five gallons of bleach into the well and pump the well to establish circulation. If the well was still contaminated, he would use 10 and then 20 gallons of bleach. Because of the time lag between disinfection attempts, health department sampling, return of bacterial results, notification and redisinfection, considerable regrowth of nuisance organisms occurred in the recirculating bore volume between the pump intake and the static water level in the well.

Without a tube to establish recirculation, no amount of bleach could disinfect the lower dead bore volume. The exact role that decomposing organic matter in the lower dead bore volume plays in supplying nutrients for regrowth of nuisance organisms is not known. Regrowth in one well was surprisingly rapid in about two weeks; regrowth above the pump intake created a chlorine demand over 1,000 ppm.

To achieve satisfactory disinfection, the entire well must be treated. The highest chlorine demand should be expected at the bottom of the well, where dirt and organic debris settle. Most wells can be quickly and surely disinfected by use of proper techniques. Wells designed or constructed with dead water pockets behind the casing may be impossible to disinfect without either eliminating the dead water pockets or making it possible to establish circulation. In new wells, fractured tablets can quickly distribute chlorine in the bore water. In wells that have nuisance organism problems, much guesswork can be eliminated by establishing circulation, measuring chlorine residuals and adding chlorine as needed to satisfy demand.

Calcium hypochlorite precautionary statements*
Hazards to humans and domestic animals
Danger–keep out of reach of children

Danger: Corrosive, causes eye damage. May be fatal if swallowed. Do not get in eyes, on skin or on clothing. Irritating to nose and throat. Avoid breathing dust. May cause burns to broken skin. Wear goggles or face shield and protective clothing when handling. Wash hands after handling.

Practical treatment (first aid): If swallowed, feed gruel, cooked cereal, or bread soaked in milk, followed by olive oil or cooking oil. In case of personal contact, remove excess material and flush skin or eyes with cold water for at least '5 minutes. For eyes get medical attention as soon as possible. Remove and wash contaminated clothing before reuse.

Chemical hazards: Strong oxidizing agent. Do not use moist or damp utensils. Contamination with moisture, dirt, organic matter, or other chemicals, or any other foreign matter may start a chemical reaction with generation of heat, liberation of hazardous gases and possible generation of fire.

Environmental hazards: This pesticide is toxic to fish. Keep out of lakes, streams, ponds, or public waters. Permits may be required for discharges containing this pesticide into public waters. For guidance contact the regional office of the Environmental Protection Agency.

Storage and disposal: Keep product dry in tightly closed container when not in use. Store in a cool, dry, well-ventilated area away from heat or open flame. In case of decomposition isolate container in open area if possible and flood with large amount of water. Do not reuse empty container. Rinse empty container thoroughly with water to dissolve all material before discarding. Place in trash collection or dispose in approved landfill area or bury in a safe place.

Directions for use

It is a violation of federal law to use this product in a manner inconsistent with its labeling.

* **United States Environmental Protection Agency**
Pesticide Registration Division

DISINFECTION OF WATER TANKS*

A.T. Palin

Tanks, whether new or old, are usually chlorinated as part of the cleansing process before being brought back into service. Disinfection should be thoroughly and conscientiously carried out since considerable contamination may have occurred. Satisfactory results are usually obtained by flushing, preferably with water that has been heavily chlorinated to, say, about 10 mg/l, and thereafter standing for about two hours filled with the chlorinated water.

Tests should then be carried out to ensure that some chlorine is still present, the so-called "residual chlorine". If all the chlorine has been lost, more should be added so that an appropriate amount remains throughout the contact period. It is considered that the residual chlorine should normally consist of at least 1 mg/l. Thereafter the tank will be emptied and recharged with the water to be stored. Wherever possible, tanks should be provided with a cover as a safeguard against subsequent pollution.

THE DISINFECTION PROCESS

This process is applied to destroy or inactivate pathogenic bacteria, viruses and other disease-producing organisms that may have gained access to the tank. To ensure the full effectiveness of the disinfectant, the tank should first be cleaned thoroughly and rinsed with clear water, the final rinse preferably containing about 10 mg/l chlorine, as previously mentioned.

If the form of the disinfectant and the type of equipment used make it difficult to chlorinate the flow of rinse water, it will generally suffice to chlorinate the first recharge, for instance by manual addition of the disinfecting agent and thorough mixing, then allowing the contact period of two hours or so, with final emptying to waste.

In the preliminary cleansing rinse, the importance of using clear water, preferably from the mains supply, and not turbid water, arises from the possibility that the presence of suspended particulate matter may interfere with disinfection by affording protection to embedded bacteria from the action of the disinfectant. Where clarification of the water is required, some simple form of filter should be adequate in these circumstances.

The most widely used disinfectant in the drinking water field is chlorine. Although current research concerns other disinfectants, either as alternatives or as adjuncts to chlorine, it is likely that chlorine will remain the primary disinfectant of choice for the foreseeable future. For large-scale use, the chlorine is usually supplied in cylinders in which the gas is liquefied under pressure. For small-scale use, such as in the disinfection of tanks, other forms of chlorine are generally more convenient to handle.

FORMS OF CHLORINE

Available chlorine

The concentration of residual chlorine is always expressed in terms of "available chlorine", no matter in what chemical form it might be present. The same also applies to the chlorine compounds used in water treatment, such as sodium or calcium hypochlorite. The available chlorine content of chlorine itself is by definition taken as 100 per cent. The concept of available chlorine is to some extent an artificial one but it remains the standard form of expression for the strengths or capacities of chlorinating chemicals as well as for the doses in which they are applied and for the residues which remain in the water. Doses and residuals are expressed in terms of milligrams chlorine per litre of water. The chlorine content of chlorinating chemicals is given as per cent of available chlorine.

In assessing the costs of chlorine from different commercial products, a knowledge of their available chlorine content is essential, as will be seen from the table below.

Reagent	*Quantity equivalent to 1 kg chlorine gas*
Chlorine gas	1 kg
High-test hypochlorite (calcium hypochlorite) 65 - 70% available chlorine	1.5 kg
Chlorinated lime (chloride of lime) 30% - 35% available chlorine	3.0 kg
Sodium hypochlorite	
15% available chlorine	5 l
10% available chlorine	10 l
5% available chlorine	15 l

Solutions

These contain chlorine in the chemical form of hypochlorite and are usually prepared from chlorine and caustic soda, thus giving sodium hypochlorite. Such

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* Reprinted with permission from *Water Services* (ISSN 0301-7028), vol. 84, No. 1014 (August 1980), pp. 515-517. Copyright, Fuel & Metallurgical Journals Ltd., 1980.

solutions are alkaline and this helps preserve them. For fresh solutions the available chlorine content can be up to 15 per cent by weight, but with storage there is a gradual loss of strength, so that within three or four months up to half the available chlorine may be lost. In practice the solution may require dilution to provide more convenient application with solution-feed dosing equipment.

Sodium hypochlorite solution is sold under a variety of trade names and packing is normally in glass, earthenware or polyethylene carboys or in rubber-lined drums. Storage should be in cool, darkened areas. Care is required in handling in view of the corrosive nature of hypochlorite solutions and the consequent risk of harmful contact with eyes and skin in the event of accidental spillage.

Solids

In addition to the solutions which contain sodium hypochlorite, solid hypochlorites are available, generally in the form of calcium compounds, although lithium hypochlorite (35 per cent available chlorine) may find some application.

One of the best-known solid hypochlorites is chlorinated lime, which is also termed chloride of lime or bleaching powder. The chlorinated lime may be added after preparing a solution or direct to the water as a powder.

Fresh chlorinated lime has about 33 per cent available chlorine content but loses strength fairly rapidly on storage unless conditions are cool and dry, when the drop in available chlorine content may be no more than 1 per cent per month. Containers must be made of corrosion-resistant material and kept carefully closed.

A superior form of solid hypochlorite, known as high-test hypochlorite, is available. This is solid calcium hypochlorite produced as a free-flowing granular material or as tablets. The available chlorine content is 65 to 70 per cent. Under normal storage conditions only 3 to 5 per cent loss a year is claimed, thus giving a much more satisfactory shelf life than chlorinated lime. The calcium hypochlorite granules dissolve readily in water; the tablets dissolve more slowly, which is advantageous where a fairly steady release of chlorine is required over periods of up to 24 hours.

APPLICATION OF DISINFECTANTS

It is of first importance that the manufacturer's recommendations for the safe handling and application of the particular disinfectant used should be followed. Solutions may be applied manually, after dilution if required, or by suitable dosing equipment. The solid forms may be applied as a solution, allowing a period of standing to permit insoluble matter to settle out if solution-feed dosing equipment is used, or as solid powder or tablets. The tablets, being slow-dissolving, can be used to give a steady release of chlorine with a suitable applicator attached to the charging main or pipe.

The dosage depends upon the available chlorine content of the product being used and the volume of water being treated. The following general formula may be used for the calculation of quantities.

Let V = volume of water in litres
D = required dosage in mg/l chlorine
A = per cent available chlorine in product
Q = quantity of product required in grams

$$\text{Then } Q = \frac{V \times D}{10 \times A}$$

If volumes are given in cubic metres the formula becomes:

$$Q = \frac{100 \times V \times D}{A}$$

Example 1. What quantity of chlorinated lime (available chlorine content 30 per cent) is required to treat 6000 l of water at 10 mg/l chlorine?

Answer: $$Q = \frac{6\,000 \times 10}{10 \times 30} = 200\text{ g}$$

Example 2. What quantity of sodium hypochlorite solution (available chlorine content 12 per cent) is required to treat 18,000 l of water at 20 mg/l chlorine?

Answer: $$Q = \frac{18\,000 \times 20}{10 \times 12} = 3000\text{ g}$$

(*Note:* To convert to the approximate volume of commercial sodium hypochlorite required, multiply by 0.8; thus, 3000 x 0.8 = 2400 ml = 2.4 l.)

MEASUREMENT OF RESIDUAL CHLORINE

It is important to check the amount of residual chlorine in the water at the end of the contact period. The difference between the applied dose and the residual represents the "chlorine demand" of the water and of the impurities in the tank requiring disinfection.

Residual chlorine may exist in several different forms, which are broadly classified as "free" and "combined" chlorine. The distinction is important in drinking water chlorination, but for the control of tank and mains disinfection it suffices to measure simply the sum of these two to obtain a single reading of "total residual chlorine".

The standard method of measuring disinfectant residuals, now in world-wide use, is known as the "DPD method". For maximum simplicity and convenience in practice, the reagents are used in the form of tablets numbered from 1 to 4. The selection of tablets depends upon the extent to which the residual chlorine is to be divided into its various forms. For the control of tank disinfection only the number 4 tablet is required, that is, the test becomes a simple one-tablet procedure giving a red colour, the intensity of which is a measure of the amount of total residual chlorine present.

The readings are obtained by matching the colours produced against the appropriate Lovibond disc of permanent glass colour standards, using the Lovibond Comparator. An alternative method, a simple modification of the DPD method, is available to give an approximate measure of the total chlorine residual over the range 0 to 50 mg/l. Details of these methods are given below.

DPD method using the Lovibond comparator[1]

Rinse test tube or cell with sample of water, leaving in two or three drops. Add one number 4 tablet, crush or allow to disintegrate. Then add sample to 10 ml mark on tube, mix and allow to stand about two minutes.

Place in the right-hand side of comparator. In the left-hand side place untreated sample in a similar tube. Match the colours against the Lovibond discs, of which a number is available with different ranges. For the present purpose disc 3/40 K would be suitable, giving a range of values up to 6.0 mg/l chlorine.

Higher levels of residual chlorine will require dilution of the sample with unchlorinated water. This is carried out by first dissolving the number 4 tablet in the measured amount of dilution water, then adding sample to mark. Multiply by the appropriate factor; thus, if 5 ml dilution water is used with 5 ml sample, the factor is 2, whereby the range covered is increased to a maximum of 12 mg/l.

Chlorocol method[2]

The Chlorocol one-tablet test is a modification of the DPD method developed to provide a simple pocket kit suitable for use in controlling the chlorination of tanks. The complete Chlorocol test kit comprises 30 tablets and a stoppered plastic test tube. The test is carried out as follows:

(a) Fill plastic testtube to about 2 cm from top;
(b) Add one chlorocol tablet;
(c) Insert stopper and shake for a few seconds;
(d) Observe colour produced.

Colour	*Chlorine mg/l (ppm)*
None	absent
Faint pink to pink	0.2 to 1
Pink to red	1 to 5
Red to purple	5 to 10
Purple to blue	10 to 20
Blue to greyish green	20 to 30
Greyish green to yellow	30 to 50
Muddy brown	over 50

In testing the chlorine content of the water at the first filling of the tank, a pink or red colour will indicate insufficient chlorine. A yellow or brownish colour will indicate excessive chlorine. At the end of the contact period the test should indicate at least a pink colour.

The procedures recommended for the cleansing and disinfection of water tanks may be applied to water mains and small reservoirs. Where any doubt arises as to the efficiency of treatment, confirmation may be obtained by bacteriological examination of samples of the water.

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[1] The Tintometer Ltd., Waterloo Road, Salisbury SP1 2JY, England.

[2] Wilkinson & Simpson Ltd., 57 Queensway, TeamValley Estate, Gateshead NE11 0NS, England.

LEAK DETECTION

*J.W. Henderson**

If one looks back in history, losses in supply systems gave water authorities little cause for concern and until a leak became a burst they were often left to their own devices.

Unfortunately, as everyone knows, costs in all areas continue to rise, the demand for water increases with a greater degree of piped services in developed and underdeveloped countries, and sources become more costly and difficult to provide. Consequently, there is a need to conserve what we already have. This change has resulted in a need for more precise means of leak detection, and today there exist a number of manufacturers who have developed systems specifically to aid the water engineer in the detection of leaks.

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* Senior Export Sales Executive, Kent Meters Ltd., Luton, Beds, England. Reprinted with permission from *Water Services* (ISSN 0301-7028), vol. 83, No. 1002 (August 1979), pp. 633-635. Copyright, Fuel & Metallurgical Journals, Ltd., 1979.

Before any leak detection programme can be implemented, it is vital to ensure that the records of the pipeline system are absolutely up-to-date. Without this the chances of success are very small. Any water engineer must therefore ask himself the following questions:

- Are the maps completely up-to-date?
- Are the positions of the key isolation valves known?
- Do drawings exist for complex interconnections?
- Do facilities exist for the installation of waste-detecting water meters?

If the answer to each of the above points is yes, then the water engineer is in a very fortunate position and much of what is said in the next few paragraphs can be ignored.

In many cities of the world, water systems have grown a little like Topsy, particularly in boom periods. Simply because of sheer pressure of work, insufficient care was taken at the time to ensure that the records were updated. Furthermore, alterations over the years to roads etc. may have invalidated original drawings. Consequently, if any degree of success is to be achieved, the first efforts must be to bring the records up-to-date. Here long-serving or even retired employees can be of considerable assistance by letting them study the existing records and note down any relevant points.

Pay particular attention to old lines which have been taken out of service, since they may not have been isolated. Likewise, when new pipelines are laid down, provision is normally made for future branch connections, many of which were not accurately recorded. Consequently, years later, rather than spend considerable sums of money on location, an entirely new connection is made, leaving the blind connection untouched to develop a leak which often proves very difficult to locate.

Having brought the records up-to-date from memory, the next stage is system verification, using pipe location equipment. Today there is available, from a number of manufacturers, equipment of high quality capable of accurately locating steel and cast iron water mains. One manufacturer is Seba Dynatronic, whose products are distributed outside of Austria, the Federal Republic of Germany and Switzerland by Kent Meters Ltd., of Luton, England. This equipment is capable of locating underground pipelines with pinpoint accuracy. It must, however, be acknowledged that this system, like its competitors, is only able to locate metallic pipes. Fortunately, the use of asbestos cement (AC) and polyvinyl chloride (PVC) pipes is only a relatively recent innovation and consequently, the relevant records are likely to be complete. For the future, a number of manufacturers are actively pursuing the goal of a truly universal pipe locator.

Having finished the task of mapping and ensuring that all isolation valves have been clearly marked, the records should be studied to determine the most suitable locations for waste water meters. The application of waste water meters is discussed in the Kent publication entitled *Reduction of Waste in Water Supplies* and consequently elaboration here would be of little point.

Sometimes the insertion of a waste meter into the main presents problems and therefore, in more recent times, a new approach has been adopted using a waste-detection van. Here the area under investigation is isolated as before; however, in this case the flow is diverted up through a hydrant and returned to the system down the next hydrant. Naturally it is necessary to be able to isolate the main between the hydrants in question. Located in the van is an accurate flow meter which provides a permanent record of flow and pressure, and a rapid indication of the effects of isolating further sections of the system under investigation.

Before moving to the actual location of a leak, one point must be mentioned; this is the practice of dispensing with the waste-detecting water meter/leak detection van and endeavouring to find leaks by surveying the scheme. This method no doubt has met with success, but for reasons which will become clear later, it is somewhat hit-or-miss and is extremely time-consuming. Furthermore, the opportunity for placing flow information on record for posterity is entirely lost.

So far the methods discussed have been entirely objective and provided no short-cuts have been taken, the water engineer should have on record full details of the pipelines and of the flows in each part of the system. Leak detection, however, is much more subjective and is highly dependent on the skill of the operator. The reason for this is that present methods of leak location rely on the sound generated by the leak itself. Water at high pressure, forced out through a fracture or fault, loses energy both to the pipe wall and to the surrounding soil or rock. This energy in turn generates sound waves in the audible range, which can be detected by either mechanical or electronic transducers.

The problem is that these sounds occur at a number of frequencies which are related to certain aspects of the leak itself. The first sound usually falls in-between the frequencies of 500 and 800 Hz and is generated by an orifice-type discharge vibration. This frequency is transferred to the pipe wall and can be transmitted over considerable distances, depending on soil conditions and the material of the pipe itself, steel or cast iron being rather better transmitters than AC or PVC. Hence "listening" to valves, hydrants, etc. can be of considerable help in preliminary location efforts.

The second level of sound falls in-between the frequencies of 25 and 275 Hz and is the direct effect of the water striking the surrounding soil.

There is a third level of sound which can be best likened to the sound of a fountain, and is generated by the water swirling around in the cavity caused by the leak. Both these sounds are quickly absorbed by the surrounding soil and hence are of the greatest value in the final pinpointing of the leak.

Leak-detecting devices have been around for many years, the earliest form being the simple listening stick made of hardwood with a cup on the end to form an earpiece; another version could be likened to the doctor's stethoscope. Despite their obvious limitations, such as lack of amplification, in experienced hands they are highly effective and should not be dismissed as having no value. Against this, however, the absence of amplification and electronic filters to exclude background noise puts them at an unacceptable disadvantage and today they have been replaced by modern electronics. Even so, considerable care has to be taken in the design of an electronic leak detector; first, the design of the ground microphone is critical, as it must be highly sensitive to frequencies between 20 and 1000 Hz but insensitive to higher frequencies. The design should be such that external noise is excluded as far as possible, and it must be robust to withstand the turmoil of constant use under often the most arduous of conditions. Secondly, the associated electronics must be designed specifically to match the microphone, the filter circuits designed to accurately eliminate background general noise, the components must be of high quality and the whole encased to withstand impact and the effects of inclement weather. Finally, the earphone must have the right matching frequency characteristics. A combination which theoretically should be relatively easy to achieve, in practice is not so.

As was mentioned earlier, leak detection is subjective and even the best equipment, in unskilled hands (or rather ears), will fail in use. Training of operators is not easy and real success is only achieved through experience gained by listening to known leaks. Sound is like taste and smell–it cannot be explained, only experienced.

The point has now been reached in the survey where there is a leak in a known section of pipe and pinpointing is necessary. One method is to use what is known as the bracketing approach which, in essence, is to compare the decibel or sound level at two points which fall either side of the leak and relate the difference to the distance between the points. Unfortunately, whilst in theory this should be quite accurate, variations in the pipe system coupled with soil conditions demand that final pinpointing requires surface contact microphones.

Let us pause for a moment to consider the surface contact microphones, or geophones. Their required frequency response has already been mentioned, but the means of transmitting the sound from the ground to the microphone is of paramount importance. Each manufacturer has his own particular method and in the case of Seba Dynatronic, refinement of design has resulted in only two types of microphone to cover all requirements. In essence, one type is for hard surfaces, such as roads, pavements etc., and the other for soils. The hard surface microphone coded WIMI has a massive body with a rubber skirt around the base for exclusion of wind and other external noises. The actual sound waves are transmitted via a spring-loaded plunger to the microphone. For soft and irregular surfaces, a lighter-bodied microphone coded BOMI is used, the sound being transmitted via a three-legged foot.

As indicated earlier, leak location is not an exact science simply because the final arbiter is the human ear; further, the sound itself can and does vary, depending on conditions. What are the "conditions" to which we are referring? First, the material of the pipeline. The sound produced by a leak in an iron or steel main has different characteristics from that produced in asbestos cement or PVC. Second, the nature of the soil and the surface material are factors; hard surfaces are more efficient radiators of sound than muddy soil, and since they are generally more uniform, the final location is also more precise. A third factor is the pressure in the main itself; high pressures generate higher sound levels which, in turn, makes the pinpointing of leaks easier. To further complicate matters, changes in the pipeline configuration also produce noise and, consequently, it is of vital importance that any operator be aware of the location of bends, trees, hydrants, reducers etc., since if these are not accounted for, it could result in errors in pinpointing. This again clearly emphasizes the vital importance of ensuring that before any leak detection programme is embarked upon, the records are completely up-to-date.

In closing, it might be felt by many that because the leak detection aspect is more of an art than a science, it is not for them. In practice, however, once an operator has learnt to recognize the relevant sounds, success can go as high as 99 per cent, provided that he or she is equipped with the right tools for the job.

CORROSION CONTROL IN THE WATER INDUSTRY

*E.G. Field**

The importance of energy conservation is forever being stressed by Governments, and the scope of the implications of widening concern from the excess use of basic fuels to the wastage of manufactured goods is growing. Estimates have been made showing that 20 per cent of the world's iron and steel production is rendered unfit for its designed application by corrosion. The figure of £3,000,000,000 per annum is frequently quoted. The loss of the finished products, be it a pipeline or a motor car body, involves more than the basic loss of the ore from which the metal was derived. The metal oxide has first to be mined, reduced in a blast furnace and a metal-forming process applied to turn it into the finished product. All of these processes requiring a considerable amount of basic energy, probably derived from oil, gas or coal.

The petrochemical industries have been forced to spend considerable sums on ensuring that their products are separated from the environment and, as a result, every item of plant has an efficient anti-corrosion system applied. Because of the "harmless" nature of its product, it is probably fair to say that the water industry has tended to devote less time and consideration to the subject of corrosion prevention. However, the widespread shortage of potable water in the 1976 drought, together with rapidly rising costs in every sphere of life, has changed the situation.

Water engineers, when evaluating the costs of anti-corrosion systems, are now finding it more and more attractive to protect their high capital investment costs with a good anti-corrosion system. In addition, other situations that arise as the result of corrosion failures, and not just the obvious cost of plant replacement, are receiving more important consideration. These include the possible loss of revenue resulting from a discontinuation of service and the loss of good will resulting from inconvenience to the public.

Articles dealing with the prevention of corrosion in the water industry have appeared in various publications but it is over 10 years since a general review of techniques, particularly cathodic protection, appeared in *Water Services* or its predecessor, *Water and Water Engineering*. This article aims to describe aspects of corrosion and its prevention that affect the water industry's particular items of plant. At the same time it will describe recent developments in protection techniques and the additional problems caused by the introduction of prestressed concrete. It is written especially for the water engineer and does not aim to probe deeply into specific areas. Suitable references are provided for more detailed study.

BASIC CORROSION

What is corrosion? Corrosion may be defined as the mechanism by which any substance deteriorates and tends to revert to its original or more basic form. There are many ways by which it is initiated, but the three principle ones are:

(a) As a chemical reaction--the presence of acids or alkalis in direct contact with the metal surface;

(b) As a result of a physical variation between areas on the metal surface which may derive from temperature or pressure changes or different stress levels,

(c) By an electrochemical reaction which is caused by potential differences occurring on the metal surface in contact with a near neutral electrolyte.

This article does not deal with atmospheric corrosion. Virtually all of the problems caused by metal surfaces being in contact with water or soil are electrochemical in nature, sometimes with the added complications of other forms of attack. Different electrical potentials occur on the metal surface or a potential difference exists between one metal surface and another that are connected electrically. Whenever a continuous electrolyte is present (for all buried or immersed plant) corrosion will occur. An electrical circuit joins areas described as anodic and cathodic. Current leaves the metal surface at the anodic areas, and flows through the electrolyte back on to the metal at the cathodic areas. Faraday's laws show that the current loss coincides with dissolution of the metal (corrosion) and the familiar rust deposit is formed. Several chemical reactions are possible, depending upon the pH of the electrolyte, but a typical one is shown in figure 1. The anodic areas corrode and the cathodic areas are protected.

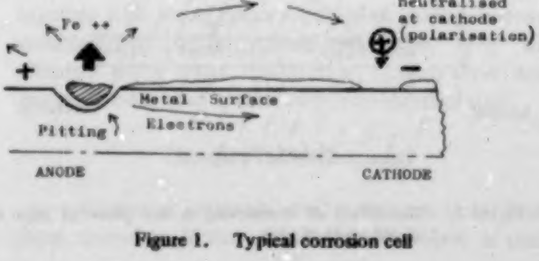

Figure 1. Typical corrosion cell

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* Director, Bosford Anode Supply Company Ltd., Winchester, Hants, England. Reprinted with permission from *Water Services* (ISSN 0301-7028), vol. 83, No. 1002 (August 1979), pp. 609-616. Copyright, Fuel & Metallurgical Journals, Ltd., 1979.

CORROSION MECHANISMS

Several types of conditions cause these differences of electrical potential, all of which can cause problems on water industry plant.

Dissimilar metals

This example is probably the most well-known and is the principle by which the torch cell battery operates. Different metals are at different electrical potentials even when placed in exactly the same electrolyte. Table 1 shows the relative positions in the electrochemical series of metals. This indicates which metal will become the anode and hence corrode, and the magnitude of the potential difference also gives an indication of the possible severity of the corrosion. Obvious examples are realized if, for example, brass valves or fittings are used with ferrous pipes. However, new and old pieces of the same materials will be at different potentials when connected together, which explains why corrosion occurs when a new piece of pipe is connected to an older pipe or when a new plate is connected into a tank to effect a repair (see figure 2).

Table 1. Practical electrochemical series of metals

Metal	*Volts*
Commercially pure magnesium	−1.75
Magnesium alloy (6% Al, 3% Zn, 0.15% Mn)	−1.6
Zinc	−1.1
Aluminium alloy (5% zinc)	−1.05
Commercially pure aluminium	−0.8
Mild steel (clean and shiny)	−0.5 to −0.8
Mild steel (rusted)	−0.2 to −0.5
Cast iron (not graphitized)	−0.5
Lead	−0.5
Mild steel in concrete	−0.2
Copper, brass, bronze	−0.2
High silicon cast iron	−0.2
Mill scale on steel	−0.2
Carbon, graphite, coke	+0.3

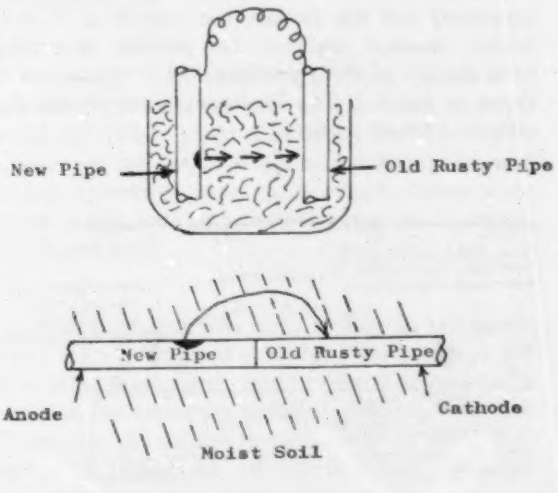

Figure 2. The effect of connecting a new piece of pipe to an old piece of pipe

Variations in soils

Different soil types have different characteristics, which means that anodic and cathodic areas are introduced whenever a pipeline or tank is in contact with different electrolytes. Corrosion cells may be "local", for instance where imported backfill is used, or "long", where geologically different soils are traversed by a pipeline, as illustrated in figure 3. The ordnance survey publishes a set of geological maps for the British Isles which are often useful in assessing the likelihood of corrosion, as the corrosiveness of various soil types is known. Tables 2a and 2b show the general classification of aggressiveness in terms of resistivity, together with typical resistivity values for various types. Another example of the same phenomenon is where free metal comes into contact or passes through concrete (for example, a pipe entering a reservoir or valve chamber). Here there is a potential difference of up to 1,000 mV, which results in current flow from the outside metal to the encased metal. Reinforcing bars in contact with outside metal result in corrosion of the latter in the same way (see figure 4).

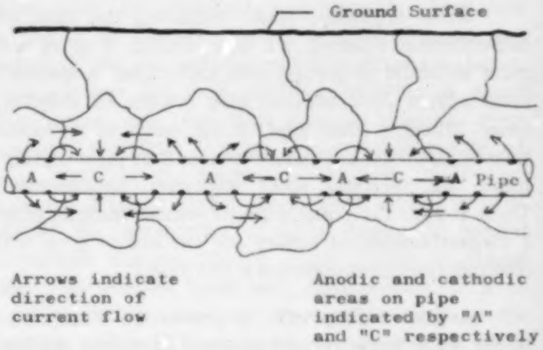
Ground Surface
A
C
A
C
A
C
A
Pipe
Arrows indicate direction of current flow
Anodic and cathodic areas on pipe indicated by "A" and "C" respectively

Figure 3. Corrosion caused by a mixture of different soils

Table 2a. Typical values of resistivity of some soils

Type of Soil	*Resistivity in ohms-cm*
Loams, garden soils, etc.	500 — 5 000
Clays	800 — 5 000
Clay, sand and gravel mixtures	4 000 — 25 000
Sand and gravel	6 000 — 10 000
Slates, shales, sandstone etc.	1 000 — 50 000
Crystalline rocks	20 000 — 1 000 000

Table 2b. Classification of soil resistivities

Resistivity in ohms-cm	*Type of soil for corrosive properties*
0 to 900	Very severe
901 to 2 300	Severe
2 301 to 5 000	Moderate
5 001 to 10 000	Mild
Above 10 000	Very mild

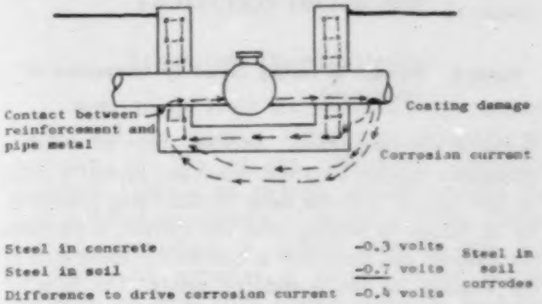
Contact between reinforcement and pipe metal
Coating damage
Corrosion current
Steel in concrete -0.3 volts
Steel in soil -0.7 volts
Difference to drive corrosion current -0.4 volts
Steel in soil corrodes

Figure 4. Corrosion of free steel with steel in concrete

Differential aeration and concentration cells

These two closely related phenomena are very similar to the last and are the result of different oxygen concentrations within the same soil or water environment. This may be due to soil compaction or ground pressure, for example where a pipeline invert level varies or where it crosses beneath a road. In water tanks and treatment plant this can occur at different water depths or where one part of the metal surface is exposed to an aerated liquid as opposed to a relatively quiescent zone which will include crevices and re-entrant angles.

Bacterial corrosion

In most cases the presence of oxygen is a prerequisite to the corrosion process. However, certain bacteria exist in oxygen-free (anaerobic) conditions and still attack steel or iron. An example is *Devibrio sulphuricans*. They are principally found in heavy compacted or clay type soils or in stagnant conditions.

Stray current corrosion

We have started on the assumption that the corrosion that is most commonly experienced is electrochemical and that whenever electrical currents are present corrosion is taking place. The mechanisms described above are based upon current generated from within the corrosion cell. However, whenever an external source of current is present, the electrical conditions are altered and corrosion is likely to occur. Current entering the structure results in protection but whenever current leaves the structure an anodic area is formed and corrosion occurs. If 1 A of current flows for one year, then approximately 9 kg of steel will go into solution. It can be seen that even if adequate precautions are taken to protect against other forms of corrosion or if soil conditions would otherwise be described as non-aggressive, rapid corrosion can still take place. Examples of stray current corrosion can often be found when other cathodic protection stations are in the immediate area, or other buried metallic plant that is cathodically protected crosses or runs closely parallel to the new plant (see figure 5). Other sources are DC traction systems, railway signalling, welding equipment or DC generators. It has also been shown that the presence of Central Electricity Generating Board 400 kV overhead transmission lines in the vicinity causes stray currents.

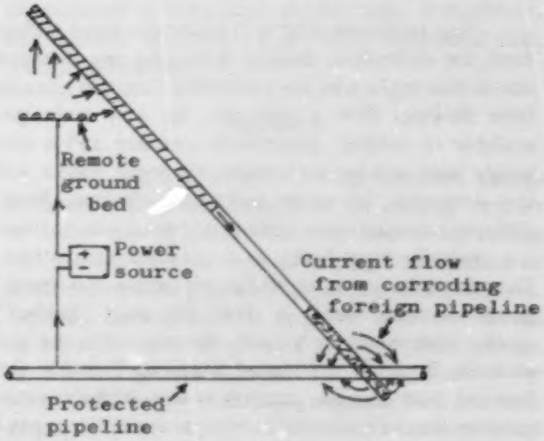

Figure 5. Damage to foreign pipeline by stray current from cathodic protection groundbed

CORROSION PREVENTION MEASURES

There are several ways of preventing corrosion, although some may not be practical or economical for the particular item of plant being considered.

Alternative materials

Some metals, principally those at the "noble end" of the electrochemical series of metals, are very stable when placed in most soils or waters and will not corrode. Gold, silver and platinum are obvious examples, together with some grades of stainless steel. Economic considerations would normally prohibit their use, although some water distribution systems have been known to have been constructed from stainless steel.

Changing the environment

At normal potentials, steel or iron can be inhibited from corroding if the pH of the electrolyte is made alkaline to within certain levels (see the standard Pourbaix diagram). This technique is the basis of certain water treatments, where chemicals are added to water storage tanks or to inhibit internal corrosion of pipelines carrying cooling water etc. However, it is generally not practical for pipelines or the external surfaces of storage tanks because of the large amounts of soil to be treated, or where potable water is stored or carried.

Design

The engineer can often take precautions during the basic design to minimize the possibility of corrosion, for instance by avoiding crevices or re-entrant angles in tanks or the coupling together of dissimilar metals. Steel or iron entering concrete should always be kept clear of reinforcing bars by at least 50 mm of cover.

Coating/wrapping

This technique aims to separate the metal surface from the electrolyte, thereby destroying any electrical circuit that might arise and preventing corrosion currents from flowing. This is generally the only technique available to combat atmospheric corrosion and is also widely used as a barrier between the metal surface and the electrolyte for water tanks and pipelines. Many different manufacturers' systems of several general types are available, some being more efficient than others. The gas industry is currently pioneering the epoxy powder system, which is about the most "perfect" coating system yet developed. However, it is not yet generally in use in the United Kingdom. Probably the best and most common coatings in use within the water industry are the combination coal tar enamel or epoxy/fibreglass layer wrap for pipelines and the coal tar epoxy system or galvanizing for tank surfaces.

None of the types above provide the perfect barrier between the metal surface and the electrolyte, and all are dependent upon a very rigid surface preparation specification without which a good coating is a waste of money. Shotblasting to SA 2½ is generally required as a minimum and this usually costs considerably more than the cost of the coating itself. Holiday detection techniques are utilized to ensure that the coating is in its best possible undamaged condition before final commissioning, but even then damage and deterioration occur in service. Figure 6 illustrates this effect with ground movement of cohesive type soils damaging pipe coating.

Cathodic protection

Because they can never be made perfect and completely separate the metal surface from the electrolyte, coatings can never entirely eliminate corrosion. A correctly designed cathodic protection system can guarantee freedom from electrochemical corrosion since it effects a reversal of the natural disassociation phenomena. Another piece of metal is introduced into the electrical circuit and current is made to flow from it onto the metal surface being protected. As all current is flowing onto the surface, it becomes the cathode and corrosion is completely eliminated at the expense of the introduced anode. The flow of current onto the surface has the effect of lowering the surface potential and by this means the effectiveness of the cathodic protection is measured.

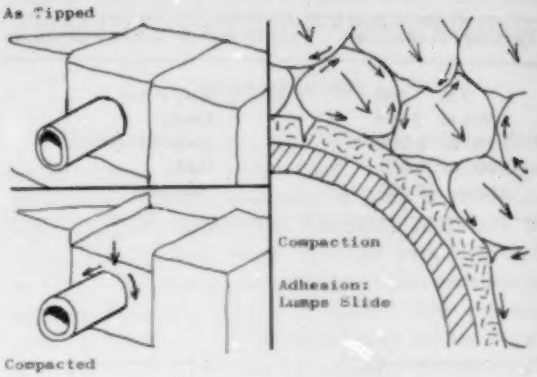

Figure 6. **Damage to coating caused by compaction of cohesive soil**

Sacrificial anode system

There are two types of cathodic protection system. Sacrificial anode systems use anodes made from metals that are more reactive than the metal to be protected. Because of their relative position in the electro-chemical series of metals, a potential difference exists between them, which causes a small electrical current to flow. As it gives up current, the anode corrodes or sacrifices itself; hence the name of the system. In practical terms the choice of anode material is limited to magnesium, zinc and aluminium alloys. There is about a 1,000 mV potential difference between steel and magnesium, which means its current output is greater than zinc or aluminium where the available driving potential is only about 500 mV. Since by Ohm's law the available current is calculated by dividing the driving potential by the circuit resistance, it will be seen that the current output of sacrificial anodes is generally limited to up to 100 mA for magnesium in most common soils, which means that their economic use is limited to low-current demand applications. Because their driving potential is even lower, zinc and aluminium anodes are generally limited to sea water or very low resistivity waters or soils. The spread of current from sacrificial anodes is also only effective over short distances.

Impressed current systems

Impressed current systems utilize anodes that are basically inert or have a very low dissolution rate.

They also have a small or an opposite potential difference to steel or iron and an external source of current has to be supplied. This is usually fed from a transformer rectifier unit and the most common anode materials are 14 per cent silicon iron for land-based structures and platinized titanium or silicon iron for use in water electrolytes. There is no theoretical limit to the amount of current to be supplied and a single installation (consisting of several anodes) may protect many miles of pipeline or a very large tank.

WATER INDUSTRY PLANT AND PROTECTION TECHNIQUES

Storage tanks (external surfaces)

Steel storage tanks are often buried or partially buried and the external surfaces are susceptible to corrosion by any of the mechanisms previously described. Coatings are normally applied but once the tank is buried maintenance to the coating is impossible. Cathodic protection is applied wherever the soil conditions are aggressive or where external sources are likely to cause stray current corrosion. Sacrificial anodes are preferred and may be the only practical method at remote locations where external power is not available. The system should be carefully designed to ensure an adequate spread of current over the tank surfaces, including the base. Consideration should also be given to the protection of tank bases where built up from ground level. Steel tanks in these circumstances are often built upon a concrete base, sometimes bitumen-coated. Settlement often allows movement and the ingress of water resulting in attack from underneath the tank base.

Storage tanks (internal surfaces)

Internal surfaces are sometimes epoxy-painted but are often left with only the workshop primer, possibly reinforced after final assembly at site. This type of condition can be regarded as being bare steel and corrosion can be expected if the water resistivity is low. The choice of protection technique depends upon the resistivity and the size of the tank. Sacrificial anodes, generally using magnesium, are preferred. Impressed current is used where a power source is available and where large bare surfaces are to be protected. However, even with good epoxy-painted surfaces, cathodic protection is often employed as an effective insurance against failure, which would result in the need to drain the tank for repairs. In some instances this is not acceptable, as the water supply must be maintained at all times. Examples would include the sole supply to remote villages and storage tanks for fire protection sprinkler systems in buildings. The water/air interface is the most difficult area to keep free from corrosion since cathodic protection is only effective where the electrolyte is continuous. This area would remain wet as the water level changes and coatings must be locally applied.

Water treatment plant

Similar comments apply to steel treatment plant and cathodic protection can be usefully used for traditionally coated steel tanks to extend the coating life and allow the period between planned maintenance shut-downs to be considerably lengthened. Cathodic protection is not only limited to steel tanks and work has recently been carried out on a large-diameter, reinforced concrete tank with steel internal pipes and launders, etc. This was a classic example of potential difference between steel encased in concrete (the reinforcing bars) and the other steel within the tank, resulting in corrosion of the latter. Various types of coating had been tried without success and only cathodic protection solved the problem. The amount of steelwork in these large settling tanks is enormous, and cathodic protection is also more economical than traditional coatings.

Boreholes

The external surface of water borehold casings is treated in the same manner as the external surfaces of tanks and pipelines. However, even if the casings left the factory with a good coating, the method of installation results in most of the coating being removed. Cathodic protection will stop corrosion but special consideration must be given to the anode layout design so that full protection potentials are achieved at the bottom of the casing. The measurement of soil resistivity at great depths is also difficult to achieve accurately and this affects the basic system design criteria. Borehole waters are often very aggressive and the riser pipes are usually flanged ductile iron lengths. They are easily protected if sacrificial anodes are clamped around the riser on each pipe length. It is normally best to include the steel casing in the surfaces to be protected and complete electrical continuity is achieved between riser pipe lengths with the use of special serrated washers under the bolt heads. Special consideration must be given to ensure that the anode mass provided is enough to remain active throughout the design life and also that the current output is sufficient to maintain full protection. A design life of 50 years is common, and long zinc anodes are normally employed.

Pipelines (steel)

Present-day steel pipelines are usually supplied coated with the standard coal tar enamel/fibreglass wrapping. In the gas and oil industries, 100 per cent cathodic protection is applied, but the water industry has normally only adopted it where the soil aggressiveness (as measured during a resistivity survey) has indicated that corrosion is likely to occur in a very short period of time. However, the presence of stray currents and the relatively low cost of applying cathodic protection compared with the over-all project cost has meant that it is beginning to be an automatic choice. The application of cathodic protection was considered by a panel committee of the Institution of Water Engineers[1] and their report of November 1972 showed that the cost of the cathodic protection amounted to between 1 to 2 per cent of the over-all project cost. Sacrificial anode systems based on magnesium are generally used for short pipe lengths in congested areas where stray currents from impressed current systems could prove troublesome, or where no power source is available. Longer pipelines are most economically protected using standard impressed current groundbed techniques that have been in use for many years. Many miles can be protected from one groundbed which consists of a number of silicon iron anodes buried in a column of coke breeze backfill and fed from a transformer rectifier unit (see figure 7). Present-day coatings are generally much better than before and the total current demand is being reduced. New forms of groundbed construction are being evaluated and the near future will see the more widespread introduction of platinized titanium mesh anodes. These are much smaller and lighter than silicon iron anodes and installation costs are considerably reduced.

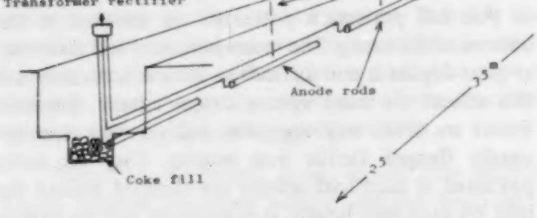

Figure 7. Typical impressed current cathodic protection groundbed

Pipelines (ductile iron)

Ductile iron pipelines are in extensive use throughout the water industry because operating pressures are usually low and the material has excellent mechanical properties. There is a widespread belief that ductile iron has some magical resistance to corrosion when compared to steel. This is often based upon evidence of old cast-iron pipes that have been in use for over 50 years. The great original thickness of the metal is probably the reason for their survival. The corrosion rate of iron and steel is very similar but in practice ductile iron is more susceptible to corrosion because it is supplied with only a thin bitumen coating whereas steel is enamel/fibreglass-wrapped.

Certain ductile iron suppliers offer free resistivity surveys with their material, which often only cover pure resistivity considerations, and recommend the use of loose polyethylene sleeving wherever very aggressive soils are traversed. Extensive experience is claimed of successful operation of this type of system but it should be remembered that the sleeving is not in intimate contact with the pipe, as is the case with normal coatings. Water can ingress when damage to the sleeving occurs, which could result in corrosion inside the sleeving. Even if the oxygen is used up, corrosion can proceed in anaerobic conditions. Once the pipe is laid with loose sleeving and problems arise, it is impossible to apply cathodic protection because the electrolyte is not in complete contact. For this reason and because only cathodic protection can guarantee freedom from corrosion, many authorities in the United Kingdom and in other parts of the world adopt cathodic protection for ductile iron pipes in very aggressive ground conditions. Several major pipeline projects have used this method of protection. Because of the larger current density required, impressed current techniques are most commonly adopted but sacrificial anodes connected to the pipeline at frequent intervals are also used. One of the first prerequisites of cathodic protection is the provision of complete electrical continuity throughout the pipeline; cables or copper straps must be bonded across every discontinuity.

Pre-stressed concrete pipelines

Pre-stressed concrete pipes are being increasingly used, as the initial study of the relative prices of alternative pipe materials shows them to be favourably placed. The service life of a prestressed pipe is wholly dependent upon maintaining the pre-stress in the circumferential steel winding. For this reason it is vital to protect the steelwork from corrosion. Steel in continuous contact with concrete does not normally corrode because of the presence of a passive oxide film. Cracking of the concrete and the presence of stray electrical currents can cause severe corrosion and cathodic protection has been successfully applied to prevent this. Sacrificial anodes are preferred because their low current output and limited open circuit potential makes it virtually impossible for hydrogen embrittlement of the reinforcing bars or disbonding to occur. Zinc anodes are normally employed in order to give a life of at least 20 years, as magnesium anodes stifle their reaction after about 12 to 15 years. Once again it is essential to provide complete electrical continuity between pipe lengths and special studs are often provided at the ends of the pipes, connected via short lengths of bond cable. Extensive experience has been gained of this type of protection system applied to a variety of structures and to pre-stressed concrete pipe in England and in several other countries.[2]

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[1] Institution of Water Engineers, Final Report of Research Panel No. 13, "Experience with the cathodic protection of mains", November 1972.

CONCLUSIONS

This article can only hope to present a very general picture of the corrosion phenomenon as it applies to the type of plant commonly used in the water industry. The mechanisms by which corrosion is instigated have been described and the common protection techniques outlined. Cathodic protection has been briefly mentioned as the only method by which electrochemical corrosion can be completely eliminated and its use has been advocated for nearly every application. In many cases its adoption can be economically justified when directly compared with the more traditional painting and coating techniques. However, the relatively low cost of ensuring that corrosion will not occur can often be justified when over-all project costs are considered in a wider context.

The water engineer would be advised to study alternative protection methods at the very outset of a project and a specialist should be consulted to ensure that all of the available alternatives are considered before detail design is started. This is particularly true with cathodic protection as savings can be made if provision is made for its adoption at the design stage.

Regular maintenance of existing anti-corrosion systems is also required if they are to continue to remain effective during the design life of the plant. This is particularly true of systems applied to buried plant which are out of sight and all too often out of mind.

The application and maintenance of a good anti-corrosion system will ensure that the particular item of plant will remain effective with the minimum costs throughout its desired life.

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[2] "Practical results from the cathodic protection of pre-stressed concrete pipeline", Roda Pipes Ltd., Milton Keynes, England, *Roda Technical Journal*, No. 64, December 1976.

DESTRATIFICATION OF RESERVOIRS—A DESIGN APPROACH FOR PERFORATED-PIPE COMPRESSED-AIR SYSTEMS

*J.M. Davis**

For many years now, artificial mixing devices have been used to prevent the water quality problems associated with thermal stratification of raw-water storage reservoirs. These problems are related to a reduction in the dissolved oxygen content of the water, particularly in the lower layers. The primary goal of an artificial mixing device is to prevent thermal stratification from becoming established and to increase the dissolved oxygen content throughout the water column.

In a previous article[1] some of the methods to improve oxygen content were briefly described, but particular mention was made of the perforated-pipe compressed-air device which is currently being promoted by the Water Research Centre for use in reservoirs in the United Kingdom. The method itself is not new and has been used successfully for over two decades, particularly in Europe, North America and more recently in Australia.[2]

In recent years the Water Research Centre has gained experience in the design and operation of perforated-pipe systems and this article summarizes this experience in terms of an empirical design procedure which can be used to identify the length of perforated pipe and compressor size needed for a particular reservoir.

The design procedure adopted is aimed at achieving complete mixing over the entire water depth and volume throughout the summer. The device is first used in spring or early summer, when the initial signs of thermal stratification appear. By mixing, when required, for periods of several days at a time, stable thermal stratification is prevented and water quality is maintained.

PROBLEMS ASSOCIATED WITH THERMAL STRATIFICATION

Raw-water reservoirs are used to store water and one of their main additional functions is to allow natural processes to purify the water before it is treated and fed to supply. The dissolved-oxygen content of the water is one measure of its water quality and in winter the stored water is usually well oxygenated. This is because the reservoir is well mixed through the action of wind-induced turbulence and convection currents, as illustrated in figure 1.

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* Water Research Centre, Medmenham Laboratory. Reprinted with permission from *Water Services* (ISSN 0301-7028), vol. 84, No. 1014 (August 1980), pp. 497-504. Copyright, Fuel & Metallurgical Journals, Ltd., 1980.

[1] J.M. Davis and R.W. Collingwood, "Destratification in reservoirs", *Water Services*, August 1978, pp. 487-490.

[2] (a) H.G. Tolland, "Destratification/aeration in reservoirs. A literature review of the techniques used for water quality management", *WRC Technical Report* TR 50, 1977. (b) J.M. Symons, (ed)., *Water Quality Behaviour in Reservoirs*, United States Department of Health, Education and Welfare, Washington DC, United States Government Printing Office, 1969. (c) F.L. Burns, "Localized destratification of large reservoirs to control discharge temperatures", *Progress in Water Technology*, vol. 9, 1977, pp. 53-63.

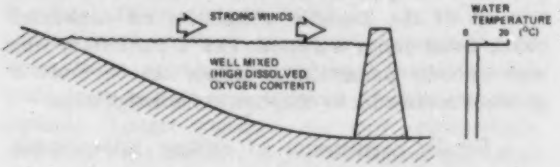

Figure 1. A well-mixed reservoir in winter

In a well-mixed reservoir any demands on dissolved oxygen are easily met through continual surface re-aeration. In summer, however, when the weather is warm and the winds are light, many reservoirs become thermally stratified, as shown in figure 2. During this time the surface layers heat up and, being less dense, float on the cooler, denser layers beneath. In time, if the warm weather continues, this process leads to the formation of three distinct layers within the reservoir: an upper layer of warm water, known as the epilimnion, an intermediate layer known as the thermocline, where water temperature falls rapidly with depth, and a bottom layer of cold water known as the hypolimnion.

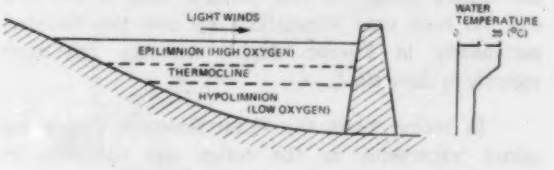

Figure 2. A thermally stratified reservoir in summer

The thermocline effectively forms a barrier between the epilimnion and hypolimnion, isolating the lower layers from the air at the surface. Organic matter, present in a newly inundated catchment or mainly composed of dead algae, decomposes and depletes the oxygen in the hypolimnion. This region rapidly becomes deoxygenated and a deterioration in water quality follows through the re-solution of iron and manganese, if present in the sediments, the production of ammonia and sulphides and the release of algal nutrients such as phosphorus and silicon. In addition, low-oxygen content can cause stress to fish populations.

The occurrence of iron and manganese in many catchments in the United Kingdom is particularly troublesome and if not removed at the treatment stage can lead to the formation of deposits in distribution pipes and dirty water complaints. Unpleasant tastes and odours may also follow from the presence of ammonia and sulphides.

If nothing is done to the reservoir and warm weather persists, the thermal stratification and low dissolved oxygen content will remain throughout the summer and into the autumn. At this time wind speeds increase and the weather cools sufficiently to cause a natural breakdown of the thermocline and a gradual return to well-mixed conditions.

The solution to the problem of thermal stratification is to prevent it from becoming well established and this can be achieved by artificially mixing the reservoir, thereby ensuring that surface re-aeration continually meets the benthic oxygen demands throughout the summer months.

THE PERFORATED-PIPE SYSTEM

Typically for reservoirs in the United Kingdom a perforated-pipe system consists of a length of pipe approximately 200 m long, closed off at one end, perforated with small holes and submerged in deep water. Clean, oil-free compressed air is pumped through the pipe and a series of bubble plumes are formed. The many small air bubbles entrain water as they rise, carrying water from the lower layers to the surface, as shown in figure 3. Mixing with the surrounding water takes place and local destratification in the region of the perforated pipe is achieved typically within a few days. General breakdown of stratification follows in time, as cooler water flows from other parts of the reservoir to replace a proportion of that carried to the surface by the air bubbles.

Oxygen demands throughout the water column are met initially through mixing, whereby the lower layers, having a low dissolved-oxygen content, are mixed with the upper well-oxygenated layers. The dissolved-oxygen content increases further as mixing continues, predominantly through surface re-aeration but also, to a very much lesser extent, through oxygen transfer from the air bubbles themselves.

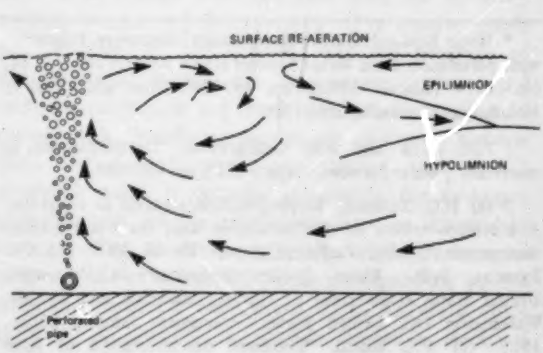

Figure 3. Circulation of water induced by rising air bubbles

Design aims

There are two main requirements of a perforated-pipe destratification device.

(a) After the onset of thermal stratification in spring or early summer, the device must be capable of mixing the greater part of the reservoir volume in a reasonably short time (say, 5 to 10 days, depending on reservoir volume) so that approximate isothermal conditions exist over the depth;

(b) During operation of the device, the oxygen demands within the water column should be met initially through mixing between the upper and lower water layers and in the longer term through surface re-aeration.

Both these criteria are catered for in the procedure which follows by designing specifically to achieve adequate mixing.

Design procedure

(a) Obtain surface area and reservoir volume as a function of depth;

(b) Assume a design temperature profile for the reservoir corresponding to conditions in spring or early summer. The choice of temperature profile ultimately decides the size of compressor, length of perforated pipe and the time required to achieve destratification. It also dictates when the compressor should be turned on, both at the start of the season and on those subsequent occasions when thermal stratification reappears. Typically in the United Kingdom, the design temperature profile will correspond to a 4°C temperature difference between the epilimnion and hypolimnion, with the temperature of the hypolimnion in the region of 8°C. For reservoirs with a volume greater than 30×10^6 m^3, the designer should consider choosing a design profile with a 2°C temperature gradient;

(c) Calculate the stability of the reservoir. Stability is defined as the minimum theoretical energy required to mix the reservoir from an initially stratified state to an isothermal state.[3]

With reference to figure 4, potential energy of

$$\text{mixed system (PEM)} = g \sum_{i=1}^{n} \rho_{im} V_i h_i \ (J) \qquad ...1$$

Potential energy of

$$\text{stratified system (PES)} = g \sum_{i=1}^{n} \rho_{is} V_i h_i \ (J) \qquad ...2$$

where,

ρ_{im} and ρ_{is} are mean water densities of each layer for the mixed and stratified cases respectively (kg/m^3).

V_i is the volume of each layer typically 1 m deep (m^3),

h_i is the height to the centroid of each layer above the bed of the reservoir (m),

g is the acceleration due to gravity (m/s^2),

n is the total number of layers.

Stability = PEM - PES (J);

Note: "s" in this article indicates time in seconds, not abbreviated here as "sec".

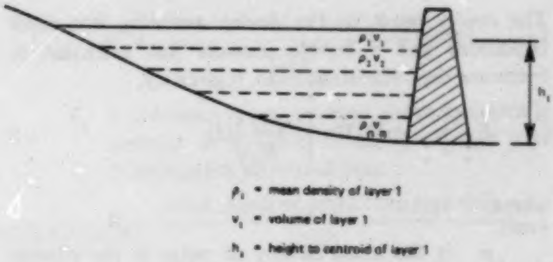
$\rho_1 v_1$
$\rho_2 v_2$
$\rho_n v_n$
h_1
ρ_1 = mean density of layer 1
v_1 = volume of layer 1
h_1 = height to centroid of layer 1

Figure 4. **Subdivision of reservoir into layers for calculation of stability**

(d) Calculate the total theoretical energy required to destratify the reservoir.

The total theoretical energy (E) required to destratify the reservoir is given as,

$$E = S + R - W \ (J) \qquad ...4$$

where,

S is the stability of the reservoir,

R represents the actual heat energy input to the water column as a result of solar radiation, and

W is the kinetic energy associated with wind-induced mixing during the period of artificial mixing. The net effect of solar heating is to increase the energy required for destratification and the net effect of wind-induced mixing is to decrease the energy requirement. For design purposes, an average value of R may be obtained at the site in question by determining the increase in water temperature in the epilimnion, and therefore the increase in stability, associated with typical summer conditions.[4] As a guide, the value of R may be calculated using 5J/m^2/d.

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[3] See reference in footnote 2 (b).

[4] P.J. Ryan, D.R.F. Harleman and K.D. Stolzenbach, "Surface heat loss from cooling ponds", *Water Resources Research*, vol. 10 No. 5, 1974, pp. 930-938.

The effect of wind-induced mixing can be very important and there is no doubt that on many occasions destratification has been greatly assisted by sudden increases in wind speed. However, it is appropriate to assume that the summer wind speeds are negligible and W is set to zero. Approximate values for stability requirements against reservoir volume and maximum depth are given in figure 5 for medium-sized reservoirs;

(e) Calculate the free air delivery required at the compressor. Field experiments carried out by the Water Research Centre indicate the following relationship.

$$\frac{\text{Energy input by device to destratify reservoir } (E_d)}{\text{Total theoretical energy required to destratify reservoir } (E)} = 20 \quad ...5$$

The energy input by the device, assuming isothermal conditions and a bubble pressure just sufficient to overcome the hydrostatic head, is given by,

$$E_d = \rho g H_o T \ln\left[1 + \frac{D}{H_o}\right] (J) \quad ...6$$

where,

ρ is the mean density of water in the vicinity of the perforated pipe (kg/m^3),

g is the acceleration due to gravity (m/s^2),

H_o is the depth of water equivalent to atmospheric pressure (H_o = 10.4 m),

Q is the quantity of free air delivered (m^3/s),

T is the time to achieve destratification (s),

D is the depth of water above the perforated pipe (m).

Using

ρ = 1,000 kg/m^3

and g = 9.81 m/s^2,

equation 5 becomes

$$Q = \frac{0.196E}{T \ln\left[1 + \frac{D}{10.4}\right]} \quad (l/s) \quad ...7$$

Equation 7 is plotted in figure 6 where the free air required can be obtained for a destratification time of five days. For a large reservoir, with a volume greater than, say, 30 x 10^6 m^3, it may be appropriate to increase the destratification time, thereby selecting a more economical compressor size. The suggested limit on minimum value for Q is 20 l/s.

(f) Calculate the length of perforated pipe required. Perforated pipes used by the Water Research Centre are constructed from black, high-density polythene pipe and consist of a series of small holes drilled manually along the length of the pipe. The diameter of the holes is such that the pressure loss associated with each one is small and that air lift is maximized. Knoppert[5] has demonstrated that for holes of 0.5 mm and 1.0 mm diameter the smaller holes result in significantly better entrainment. Cederwall[6] has shown that for hole diameters in the range 0.05 mm to 0.5 mm, the volume of water entrained is independent of hole diameter.

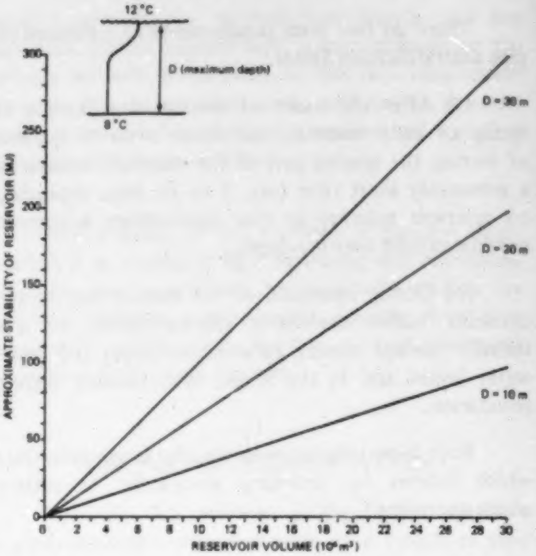

Figure 5. Approximate stability of reservoir for a 4^{o}C temperature profile

However, it is important to prevent natural blockage of the holes when the compressor is off by making the diameter as large as possible. Experience has indicated that a hole diameter of 0.8 mm is suitable.

Cederwall developed a model of plume dynamics which suggested that for a given air flow the volume pumped by entrainment increases if the perforated pipe behaves as a line source rather than a series of discrete plumes several metres apart. To achieve this a hole spacing of 0.3 m is specified.

To calculate the length of perforated pipe required, use is made of the following relationship, determined for spring conditions during field experiments conducted by the Water Research Centre:

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[5] P.L. Knoppert, *et al.*, "Destratification experiments at Rotterdam", *Journal,* American Water Works Association, vol. 62, 1970, pp. 448-454.

[6] K. Cederwall and J.D. Ditmars, "Analysis of air bubble plumes", Report no. KH-R-24, California Institute of Technology, 1970.

$$\frac{\text{Volume of water entrained by air bubbles to destratify reservoir } (V_e)}{\text{Volume of reservoir } (V)} = 2.5 \quad \text{...8}$$

The volume of water entrained by a perforated-pipe system in time T (s) may be written[7]

$$V_e = 0.486LT\left[\frac{gQ}{L}\right]^{1/3}\left[1+\frac{D}{10.4}\right]^{-1/3}\ln\left[1+\frac{D}{10.4}\right] \quad \text{...9}$$

where

L is the length of perforated pipe (m),

Q is the quantity of free air delivered (l/s) determined from equation 7,

D is the depth of water above the perforated pipe (m),

g is acceleration due to gravity (9.81 m/s^2).

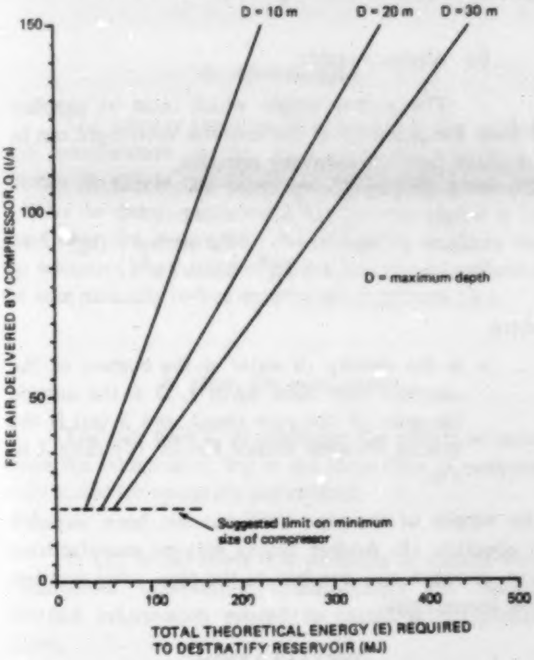

Figure 6. Free air requirements to destratify reservoir in five days

Using equation 8, the length of perforated pipe required is

$$L = 3.73\left\{\frac{V^3\left[1+\frac{D}{10.4}\right]}{T^3\,Q\left(\ln\left[1+\frac{D}{10.4}\right]\right)^3}\right\}^{1/2} \text{(m)} \quad \text{...10}$$

where V is the volume of the reservoir (m^3) and T is the time to achieve destratification (s). Equation 10 is plotted in figure 7 for selected values of reservoir volume and maximum depth. The suggested limit on minimum value for L is 50 m;

(g) Specify the air pressure requirements at the compressor and determine internal pipe diameter. The gauge air pressure at the compressor, P_c (bar), can be calculated from the following expression

$$P_c = P_h + P_e + P_f + P_b \quad \text{...11}$$

where,

P_h is the hydrostatic pressure corresponding to the maximum depth of water over the perforated pipe, i.e.

$$P_h = \frac{\text{maximum water depth (m)}}{10.4} \text{ (bar)} \quad \text{...12}$$

P_e is the mean excess pressure above hydrostatic pressure at the end of the perforated pipe section and is estimated from

$$P_e = \frac{\text{total length of perforated pipe (m)}}{150} \text{(bar)} \quad \text{...13}$$

P_f is the pressure loss due to friction and depends on the diameter, length and shape of the pipe, the internal surface roughness and the Reynolds number. It is important to minimize friction loss and for most destratification systems in the United Kingdom, pipe diameters have ranged from 38 mm to 76 mm. For economical choice of pipe diameter it is suggested that P_f does not exceed 0.1 bar per 100 m of pipe length.

$$P_f = \frac{833\ l\ Q^2}{(P_c + 1)d^{5.31}} \quad \text{(bar)—see footnote 8} \quad \text{...14}$$

where

l is the total length of pipework extending from the compressor to the end of the perforated pipe section (m),

Q is the free air supply (l/s),

d is the internal diameter of the pipework (mm), and

1 bar is taken as being equivalent to 14.5 psig or 10^5 Pa.

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[7] P.S. Bulson, "Currents produced by an air curtain in deep water", *The Dock and Harbour Authority Journal*, vol. 42 No. 487, 1961, pp. 15-22.

[8] *Kempe's Engineers' Year Book for 1978*, vol. 2, Morgan-Grampian (Publishers) Ltd.

Because P_f depends on a value for P_c in equation 14, a first approximation for P_c must be made and if necessary corrected later.

i.e. P_c (estimate) = $P_h + P_e + 2$ (bar) ...15

P_b is the pressure drop associated with bends in the pipework, valves and air filters. This will depend on the particular pipe layout and type of filters used. However, a reasonable estimate for P_b is 1.5 bar;

(h) Check that length of perforated pipe is sufficient to meet the specified air delivery.

In some cases the length of perforated pipe identified, and therefore the number of holes, will not be sufficient to meet the air delivery capability of the compressor. Figure 8 may be used to determine the discharge through each hole for the particular depth of water in question. Note that P_{ha} and P_{ia} are the absolute hydrostatic pressure and the mean internal absolute pressure within the perforated pipe section respectively.

i.e. with the notation of equation 11,

$$P_{ha} = P_h + 1 \quad \text{(bar)} \qquad \text{...16}$$

$$P_{ia} = P_e + P_h + 1 \text{ (bar)} \qquad \text{...17}$$

The number of holes in a perforated pipe section is $\frac{L}{0.3} + 1$, where L is the length of perforated pipe in metres. The number of holes multiplied by the discharge per hole determined from figure 8 will indicate if the perforated section should be increased to satisfy the quantity of air delivered by the compressor;

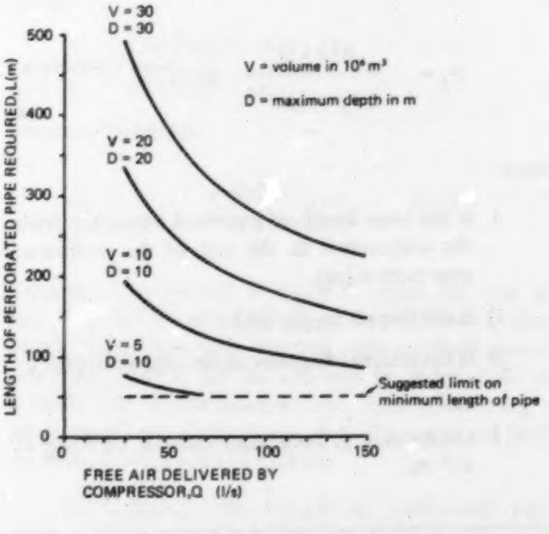

Figure 7. Length of perforated pipe required to destratify in five days

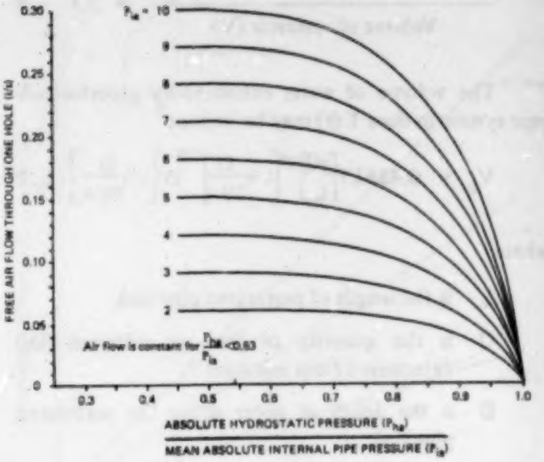

Figure 8. Free air flow through one hole of a perforated pipe

(i) Anchor weights.

The anchor weight which must be supplied to keep the pipework in the reservoir submerged can be calculated from the following equation.

$$\text{Weight of anchor block in air} = \rho \left[\frac{\pi D^2 S}{4 \times 10^6} + \text{volume of the anchor block (m}^3\text{)} \right] \text{(kg)} \qquad \text{...18}$$

where

ρ is the density of water at the bottom of the reservoir (say 1000 kg/m³), D is the outside diameter of the pipe (mm), and S (m) is the spacing between anchor blocks, typically 1 to 3 m.

The weight of the pipe itself has not been included in equation 18. Anchor blocks may be manufactured from concrete and attached to the pipe, using stainless steel connections.

INSTALLATION

The previous section has described a design procedure for determining the compressor size and length of perforated pipe necessary for destratifying a reservoir.

The site installation of such a system is straightforward but the approach will be different, depending on whether the reservoir in question currently exists or is under construction. In the former case no provision has necessarily been allowed for a compressor housing and the perforated pipe must be installed from a boat. In the latter case the pipework is installed in the dry and the layout of connecting pipe and location of the compressor become an integral part of the dam construction.

However, certain important aspects of the installation will be common to both cases.

1. *The compressor*

Where possible, the compressor should be electrically powered. In certain cases this may not be feasible and a portable compressor will be the only option. However, although portable compressors have been successfully used in the United Kingdom, they are not suitable for long-term use, particularly with regard to the demands of refuelling.

2. *Air-filtering*

The compressed air should be clean, being filtered of both particulate matter and oil vapour. There are several excellent commercial filter units available which guarantee a clean air supply.

3. *After-cooling*

The primary function of after-cooling is to reduce the temperature of the air leaving the compressor before it enters the pipework. In certain cases this will be necessary, particularly if polythene pipe is to be used near the compressor. An alternative would to use an adequate length of steel pipe so that the air is allowed to cool naturally before entering the polythene pipe.

4. *Siting the compressor*

The aim here is to minimize the effects of noise from the compressor, but at the same time to maintain easy access for operation and control.

In (1) to (4) above it is advisable to consult with commercial compressor manufacturers for further detailed information related to particular compressor types.

5. *Manufacture and location of perforated pipe*

All the pipework within the reservoir can be made from high density black polythene pipe of either class C or class D, which has maximum pressure ratings at 20°C of 8 bar and 11 bar respectively. It is readily available in coiled lengths up to 100 m and special orders for longer lengths are considered by certain manufacturers. The lengths of pipe can be joined on site, using special butt-weld equipment or standard couplings.

On arrival at site the pipe is uncoiled and laid out, either in its final position in the case of a reservoir under construction, or along the dam wall of an existing reservoir. Portable high-speed drilling equipment is used to drill the holes at 0.3 m centres along the top of the pipe. Holes must be clean and clear of swarf and are formed using a number 60 (1 m diameter) drill which leaves a hole of approximately 0.8 mm diameter. Finally a standard stop-end fitting is inserted in the end of the pipe.

Most installations will be in impounding reservoirs, and the perforated pipe should be positioned and anchored at 1 to 3 m centres along a line perpendicular to the dam wall in deep water. The perforated-pipe section itself should start approximately 100 to 200 m from the dam structure and, depending on the site situation, will be located in the general region of supply draw-off. During operation the pipe should be about 300 mm above the general bed of the reservoir.

6. *Back-siphoning*

It is important that suitable non-return values and stop valves be installed within the pipework to prevent possible back-siphoning of water at times when the compressor is not in operation.

7. *Monitoring and operation*

Efficient use of the destratification system relies on monitoring water temperature and dissolved oxygen concentration near the supply draw-off. Measurements should be taken at 5 m intervals or less over the depth and this may be done manually at weekly intervals or with automatic sampling equipment (which includes a calibration facility) at more frequent intervals. In either case, monitoring should commence early in spring and continue through the summer. The compressor is turned on when either initial thermal stratification occurs or the oxygen content of the hypolimnion falls to 50 per cent of saturation. The compressor can be turned off when the reservoir becomes isothermal and the oxygen content reaches an acceptable level.

8. *Maintenance*

Regular maintenance of the compressor system should be arranged and during the winter months it is recommended that the compressor be turned on for about an hour at two-weekly intervals to keep the holes in the perforated section clear of debris.

EQUIPMENT COSTS

Approximate unit costs for compressors and polythene-pipe sections are given in tables 1 and 2 respectively.

Table 1. Approximate compressor costs

Compressor type	*Free air delivery (l/s)*	*Working pressure (bar)*	*Motor power (kW)*	*Approx.* cost (£)*
Rotary sliding vane	25	7	11	1 800
	40	7	12	2 300
Rotary-screw package including air filtration	56	7	22	4 000
"	73	7	30	4 300
"	113	7	45	6 400
"	137	7	56	7 250
"	203	7	75	12 000
"	305	7	112	16 400

Note: * most of this cost information was supplied by Compair Industrial Ltd, Weybridge, United Kingdom.

Table 2. Approximate costs of high-density polythene pipe

Internal pipe diameter (mm)	*Maximum working pressure at 20° C*		*Approx. cost per metre (£)*
	Class C (bar)	*Class D (bar)*	
25.4	8	11	1
38.1	8	11	2
50.8	8	11	3
76.2	8	11	5

The total cost of a destratification system will include installation charges, which are related to particular site conditions. However, as a guide to overall costs, a system installed in a reservoir under construction and consisting of a 500 m polythene pipe (50.8 mm internal diameter, 300 m perforated) and a compressor delivering 100 l/s of filtered free air compressed to 7 bar will cost in the region of £20,000. Running costs are likely to be under £2,000 per annum.

DESIGN EXAMPLE

1. Reservoir details

Maximum volume of reservoir	20×10^6 m^3
Maximum depth	20 m
Maximum surface area	1.2×10^6 m^2

2. Design temperature profile

Depth	Temperature °C
Surface to 4 m	12
4 m to 12 m	12 to 8
12 m to 20 m	8

3. Energy requirements

Stability of reservoir (from figure 5) = 135 MJ

Heat energy input over five days as a result of solar radiation $5 \times 5 \times 1.2 \times 10^6 = 30$ MJ

Total energy required to destratify reservoir = 135 + 30 = 165 MJ

4. Air flow

Free air required to destratify in five days (from figure 6) = 70 l/s

5. Pipe length

Length of perforated pipe (from figure 7) say 250 m

6. Pressure requirements

Hydrostatic pressure P_h (equation 12) $\frac{20}{10.4} = 1.9$ bar

Excess pressure at end of perforated pipe P_e (equation 13) $= \frac{250}{150} = 1.7$ bar

Estimate pressure at the compressor P_c (equation 15) $= 1.9 + 1.7 + 2 = 5.6$ bar

Friction loss over total length of pipe of, say, 400 m with an internal diameter of 50.8 mm, P_f (equation 14) = 0.2 bar

(friction loss over 400 m of pipe with an internal diameter of 38.1 mm, $P_f = 1.0$ bar)

7. Pipe selection

Select pipe with an internal diameter of 50.8 mm

Check estimated pressure at compressor from equation 11,

$$P_c = 1.9 + 1.7 + 0.2 + 1.5 = 5.3 \text{ bar}$$

This is close to the original estimated above and so a pressure of 5.3 bar is chosen at the compressor

8. Check air flow through perforated pipe

Number of holes in perforated section $= \frac{250}{3} + 1 = 834$

With reference to figure 8 and equations 16 and 17,

Absolute hydrostatic pressure $P_{ha} = 2.9$ bar

Absolute mean internal pressure along perforated pipe $P_{ia} = 4.6$ bar

and therefore, $\frac{P_{ha}}{P_{ia}} = 0.63$

Estimate of total air flow under these pressure conditions (from figure 8) $0.13 \times 834 = 108$ l/s

This exceeds the air delivered by the compressor and therefore it is not necessary to increase the length of perforated pipe specified earlier.

9. Anchor weights

Weight of anchor in air (equation 18) assuming an anchor block of 0.15 m^3 spaced at 2-m intervals is 9.12 kg.

(The outside diameter of the pipe is 60.5 mm)

10. Summary of the major equipment required

Compressor: 70 l/s of free air compressed to 5.3 bar and suitably filtered

Pipework: 250 m perforated pipe made from high-density polythene, Class C, with an internal diameter of 50.8 mm and drilled at 0.3 m centres with a number 60 (1 mm diameter) drill

GLOSSARY OF COMPUTER LANGUAGE

– From *Water Well Journal* (USA), August 1980

applications software: Programmes designed to provide specific business operations such as accounts receivable, payroll and general ledger.

backup storage: Copies of stored data. Used as a precaution against damage or loss, they are magnetic tapes or discs.

BASIC: Acronym for "beginner's all-purpose symbolic instruction code", a programming language common to small computer systems.

batch system: Computer system that allows large amounts of input and output data to be processed on a delayed basis. Data can be entered at different times with all printed results produced simultaneously later.

baud rate: The rate of data movement between two devices. For example, between a CPU and a disc memory. The greater the baud rate, the faster you can transmit information.

bit: The smallest unit of information dealt with by a computer. A bit can have one of two values, represented in electrical terms as "on" and "off."

bubble memory: Just entering the market, this memory form utilizes magnetized "bubbles" for information storage. Stored information is retained when electrical power shuts down.

byte: A series of eight bits. A byte is the amount of space needed to store a character–a letter or number.

cathode ray tube (CRT): Much like a TV set, the video screen that displays characters in the patterns ordered.

central processing unit (CPU): The heart of the computer. It provides the circuitry for the actual computation and control commands and channels data into and out of the computer. Now frequently referred to as the microprocessor unit (MPU).

computer: An electronic machine that manipulates data at high speeds in programmed sequential order.

computer languages: The symbols and their structuring for computer programming, or software.

data base management: System of storage and retrieval allowing quick access to data files and efficient compilation of reports.

debugging: The removal of errors in a computer programme.

dual density: Method used to store on a disc twice the standard amount of data.

floppy disc: A flexible disc storage medium with a capacity ranging from 250,000 to one million bytes.

hard disc: Similar to a floppy disc, but larger, more costly, faster and having tremendous storage capability (5 million bytes and up).

hardware: The actual machines of the computer system.

interactive system: Helpful in decision-making, it gives the user immediate results, allowing for an interchange of information between the user and machine.

magnetic tape: Used primarily for backup storage, the reel-to-reel format is most common in business computer systems. Allows only sequential access to storage.

memory: Part of the CPU holding processed information.

modern: Allows a computer to be tied into a telephone line for long distance data transmission.

peripheral equipment: Input-output and data storage devices, such as keyboards, video screens, printers and disc drives.

service bureau: Company that provides computer use for a fee, freeing a client from having to purchase any computer equipment.

software: The programmes that instruct the computer how to respond to specific commands.

storage: The devices that store both data and software. Examples are discs and tapes.

system software: Instructions that control the functions of the machine, such as the translation of commands into a form that the CPU can use.

terminal: An input or ouput station. Common example is the video screen with keyboard.

time sharing: Access by many users simultaneously to a single CPU. Each client has a premises.

ASIAN-PACIFIC EXPERIENCE

SMALL HYDRO PLANTS IN CHINA

*N.P. Koh**

When collective farms first evolved in China, enterprises that demanded capital and collective efforts became possible. Irrigation was undertaken on a limited scale and the harnessing of water power was attempted. Lack of material resources was no restraint to the villagers. They made the blades of water-wheels out of wood and wires for the generators out of old coins. Electric light encouraged social activities in the villages and electric motors brought both leisure and progress to the countryside. As wealth gradually accumulated, it was possible to use modern machinery and techniques. At this stage the water-wheel turbo-pump and the induction generator were developed. They constituted a cheap combination: water from a low fall was delivered to a spot high enough to run down to the fields, and the induction generator belted to the shaft of the turbo-pump generated electricity for light and power.

STANDARDIZED EQUIPMENT

The time had then come to build water-wheel turbines and synchronous generators. A department was established to design and provide the factories throughout the country with complete sets of drawings to make the units. Remote supervisory control systems were then added to the machines. A range of sizes and ratings were developed from these individual turbine and generator designs. Now the water-wheel generator sets cover 12 to 5000 kW and speeds ranging from 1500 to 214 rev/min.

The design of fixed ranges and standardization have meant that standard manufacturing drawings can be supplied to the factories building small water-wheel generator sets; without these it would not have been possible for factories without experienced designers to make the equipment. Factories throughout the country producing equipment to the same drawings brought about nation-wide standardization, and this not only speeded up production, but also facilitated the planning and design of hydro stations. Spare parts could be obtained from any one factory for sets produced by any other.

The following is an outline of the standardized unit equipment and the principles behind their design.

Water-wheel turbines

We are taking as an example turbines for heads from 2 to 260 m and flows from 0.12 to 2.5 m^3/s, for ratings of 12 to 5000 kW. The range is covered by eight series totalling 32 types, as follows:

	Number of series	*Number of types*
Fixed blade propeller	2	10
Francis	3	12
Pelton	3	10

The propeller turbines cover heads of 2 to 14 m; Francis: 6 to 80 m; and Pelton: 100 to 260 m. Blade angles for the propeller vary in steps from 0° to 20°. Guidevanes, stayrings, cover plates, bearing, etc., are standardized for each Francis runner diameter. Jet nozzles and needles, elbows and deflection plates are also standardized for the Pelton.

The total of 32 types have been chosen to obtain minimum cost for the area of heads and flows to be covered by the series.

Governors

Two types of governor have been developed for the series 12 to 5000 kW, one for a range of 35, 75, 150 and 300 kg-m, hand-adjusted, and the other for a range of 300, 600 and 1000 kg-m, suitable for remote control.

Snychronous generators

Economy in material demands that the generators run at the highest possible speeds consistent with material strength. Thus the highest speed for the smallest outputs is 1500 rev/min, while that for the rest of the series is 1000 rev/min. The arrangement of water-wheel generators has to be modified with the speed and diameter, and the range of 12 to 5000 kW, with speeds from 1500 to 214 rev/min, is divided into five series, as follows:

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* Tianjing Electro-drive Research Institute, Tianjing, China. This article is reprinted with permission from *Water Power & Dam Construction* (ISSN 0306-400X), vol. 32, No. 7 (July 1980), pp. 31-32. Copyright, IPC Business Press Ltd., 1980.

Output (kW)	*Number of poles*	*Layout*
12-75	4-8	Both horizontal and vertical
100-160	6-8	Both horizontal and vertical
200-630	6-20	Horizontal only
800-2000	6-12	Horizontal only
1000-5000	12-20	Vertical only

Each frame has from two to four core lengths and each core length has the range of speeds listed above, thus reducing the number of framesizes to a minimum. Only two generator voltages (400 and 6300 V) are adopted, in keeping with transformer and switchgear system voltage standardization.

Apart from layout, which mainly affected the stator construction, the series required three types of rotor construction. It was also found necessary to limit the ratio of maximum to effective head for the turbine, to make it possible to design the generators to a uniform allowable stress at runaway speeds. This incidentally led to stations being designed to standardized heads. With the help of a computer, the number of stator and rotor core punchings have been reduced to a minimum to speed up production.

Excitation systems

Semi-conductor static excitation systems are replacing the direct current (DC) exciter. However, the cost of these systems must be in reasonable proportion to the cost of the generator. Hence, small generators are fitted with simple excitation systems, which become more complex with increased generator outputs. Modern static excitation systems are capable of giving high ceiling voltages without being too complex in their design. This has made it possible for even small generators to handle the direct-on-line starting current of induction motors of comparable outputs, which is a strong reason for using static systems. For larger ratings, excitation systems are designed to enable the generators to share reactive power in the ratio of their capacities when running in parallel. They must also be able to maintain ceiling voltages for the required duration for short-circuits close to the generator terminals.

For the 12 to 75 kW series, the generator stator slots carry an auxiliary winding connected in series with a tapping on a reactor through which flows the generator armature current. This voltage with current compounding is rectified to supply the generator field current. For the range of 100 to 320 kW 400 V generators, static excitation uses single thyristors, thus dispensing with reactors or transformers. For the 400 to 2000 kW 6300 V high-speed horizontal-type generators, brushless alternating current (AC) excitation systems are used, while vertical low-speed 100 to 5000 kW generators use static transformer excitation systems.

Control systems

Besides automatic speed and voltage regulators, automatic starting of the water-wheel generator sets can be provided. The starting can be initiated from the control board on the turbine floor, or from the station control room set apart from the machines in the station. In the latter case a board with mimic diagrams, placed behind the control desk, displays the system conditions. Instruments show the voltages, currents, power and frequency, among other indicators, and indicating lights and alarms are provided to assist the operator.

Some stations are connected with the system control centre through a carrier-frequency link which, among other uses, serves both as remote indication of station outputs, and as a telephone link. A few stations are equipped with supervisory control, and computer control is being developed for cascade hydro stations.

OTHER FACTORS INFLUENCING DEVELOPMENT

Among the factors contributing to the rapid development of small hydro-electric power stations in China, the following should also be considered.

Irrigation work carried out annually throughout the country, and civil engineering works, often leave space for electric generating plants. Output is consumed near the station, saving transmission costs. The operation of small hydro stations is simpler and cheaper than that of diesel plant. There is a water resources bureau in each of the 2500 or so districts throughout the country, whose duty among other things is to investigate the water resources and potential hydroelectric energy in each district. The supply of complete hydroelectric equipment, besides the benefits mentioned earlier, accelerates installation schedules.

Water stamp issued in Botswana

A new stamp has been issued illustrating the importance of ground-water development in the economy of Botswana. The 40-tebi stamp features a water-well drilling rig which has been in operation since 1978 for the Ministry of Mineral Resources and Water Affairs. A second rig has been ordered to aid production for the national programme being implemented during the United Nations Water Decade (1981-1990).

-- From *International Water Report* (USA), Autumn 1980

SMALL SCHEMES IN NEW ZEALAND*

Many small hydro stations have been built in New Zealand since the first station was built in 1880.

The first stations supplied power to gold mines and saw mills; later stations were built primarily for supply to isolated communities, but over the last twenty years the majority have been built by supply authorities to provide their consumers with power at a cost below that of power from the grid.

State (i.e. official) interest was originally passive, but as consumer demand outstripped the capacity of the central Government supply, there was active support and finance for local schemes.

In general, small hydroelectric projects in New Zealand came into being if the local community was enthusiastic, if there was a suitable site and if finance was available.

The initiative shown by supply authorities in remote areas, together with subsidies from the very successful Rural Electrification Scheme, meant that by 1932, 93 per cent of the population had electric power, even though large areas were not served by the grid.

Lloyd Mandeno, OBE, who was the founder of this type of community project, also pioneered the utilization and development of single-wire earth return transmission lines, a major factor in reducing primary distribution costs.

New Zealand small hydroelectric generating schemes are usually defined as less than 50 MW and mini as less than 1 MW. About 60 have been built or are under construction and more are planned, but there is now some restraint on official funding because of a recent reduction in load growth.

The construction of small schemes is not subsidized and stations produce electricity at a lower price than it is available from the State. Thus, in effect, they must compete with the average cost of production in the State system; this is made rather difficult since the State naturally has first call on the best sites and builds much larger stations, with all the benefits of scale.

The table lists the number and output of these schemes and compares them with the stations owned and operated by the State.

Small hydro schemes in New Zealand

	Output range	*Number of stations*	*Total (MW)*
Supply authorities			
	0-10	40	42
	10-50	2	75
Privately owned			
	0-10	6	5
New Zealand Electricity			
	0-10	2	9
	10-100	11	623
	100-1 000	12	3 240

A further 16 schemes with an output of 132 MW are under construction, and 12 more totalling 104 MW are proposed.

ENGINEERING ASPECTS

One factor which was all-important in the construction of the early schemes was low cost. To this end builders used intakes, head- and tail-races and pipelines which had been used during the gold rush and were afterwards abandoned. Turbines were bought second-hand or built locally and transmission lines were made of fencing wire.

These stations were designed by innovative, versatile engineers on the basis of experience, common sense and a wide appreciation of all aspects of engineering, from geology to electrical machines.

As demand and community involvement, as opposed to private individuals or mines, increased, so did the ability to pay for more modern equipment and technical expertise. This culminated in the construction of very efficient small schemes designed and supervised by experienced consultants. As New Zealand is in an active volcanic area, all structures and equipment have to be built with this in mind and engineers have become very conversant with the special requirements for dams, structures and equipment.

The more recent schemes have usually been designed to operate in parallel with the grid and to produce the maximum amount of power at the lowest possible cost. The need to maximize output has added a second factor to the designer's aims: that of high efficiency.

Detailed studies are therefore carried out to determine the optimum dam height, installed capacity, penstock diameter etc., and the machines' specifications incorporate substantial efficiency penalties.

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Most small schemes in New Zealand obtain their generating head by river diversion and usually consist of a diversion structure, a canal, intake, penstocks and powerhouse. Storage is reduced to a minimum unless there is a multipurpose use for the water, a factor which is always considered in feasibility studies. Occasionally a fall will be introduced into the supply pipeline of an irrigation project to allow construction of a small generating plant.

PROJECT EVALUATION

Engineers carrying out surveys for small schemes have developed methods which quickly pinpoint the most advantageous or most economical sites. This can be of critical importance in feasibility studies, where there is often no local specialized knowledge available. Thus the ability of an individual engineer to evaluate site potential rapidly becomes important where the number of specialists available is limited either in number or by money. In this respect the experience gained by New Zealand consultants accustomed to working alone or in very small teams is invaluable.

One of the techniques is the use of conceptual catchment models of rainfall runoff. It is especially appropriate if long-term records of daily rainfall are available for the supplying catchment, but few of river flow. This situation is common in the more remote regions of New Zealand and neighbouring countries, especially in catchments not significantly influenced by high-altitude snows or rainfall.

Fitting model parameters and checking model performance require some four to six years of recorded flow data. If the model reproduces recorded flow with an acceptable degree of reliability, it can be used with long periods of historic input information to produce a synthetic flow record for the same period.

Dimensions of machines and their characteristics for project evaluation are rapidly calculated from computer programmes similar to those which have appeared in *Water Power & Dam Construction*. These programmes allow rapid sizing, optimizing and costing of units and powerhouses.

STRUCTURES

Intakes are the Achilles' heel of small hydro schemes and their design is of crucial importance. For instance, on the west coast of the South Island, where rivers are steep with high flood and large bed and debris load, the 11 m^3/sec Kawaka intake is of the stream-bed type with inclined self-cleaning bars combined with a stilling pond and the 2 m^3/sec Big Waihinini intake includes a self-flushing sediment basin. For very small intakes of 0.5 m^3/sec, a skip design has been developed, where water and sediment jump right over the intake during flood flows. Allied to a riprap lined stilling basin, this has developed into cheap and very effective intakes for maintenance-free operation in remote locations.

Lower down the same project, concrete slide gates have been used for penstock intakes. These 2.5 m^2 gates are hydraulically operated with an automatic over-velocity trip to protect the penstock. Flexible couplings with up to 1° deflection per joint have been used for the 1.8 m-diameter penstock, which allows it to follow land contours, providing an environmentally acceptable topographical blend while saving on anchor blocks and erection time. Field welding and painting are also avoided and this, as with many other solutions adopted for small schemes, is aimed at reducing site work to the minimum.

In New Zealand there are large areas of soil containing a high percentage of pumiceous volcanic ash, similar to that which occurs widely in Africa and Latin America. This soil commonly has a submerged density of 500 kg/m^3, about half that of a siliceous sediment. It is particularly susceptible to hydraulic uplift and requires special techniques to maintain stability against pressure. One method of doing so is to lengthen the seepage path through foundations, thereby reducing uplift pressure at vulnerable exit points, combined with filtered pressure relief drains. The necessity to provide flood banks and anti-erosion structures has given local engineers wide practical experience of construction work in these difficult conditions.

In the Wheao small scheme for instance (figure 1), the key to economic success of part of the project was to provide a 4.5-km canal across volcanic plains at reasonable cost, since a concrete-lined canal was prohibitively expensive. This canal is being constructed of natural materials with flat batters (3:1) to allow a blanket of ash to be laid over the subgrade. Since this material is erodable, it is being protected with a top blanket of river shingle. The result is a wide, low-velocity canal with enough storage to provide a small amount of additional generation over the evening peak period.

Civil engineering economy is achieved by emphasis on modern foundation and structural design as opposed to more conservative, heavy civil engineering foundations. Reinforced concrete is preferred to mass concrete structures, framed structures and arches to cantilevers, the inherent strengths of natural ground mobilized by rockbolting, surface protection and drainage techniques to supportive structures. The result is that the engineering effort is generally high. A good example of this is the Lower Mangapapa dam, at Tauranga, North Island.

This site is topographically favourable for an arch dam, the height to crest-width ratio being 1 to 1.5. The foundation rock is a volcanic rhyolitic ignimbrite

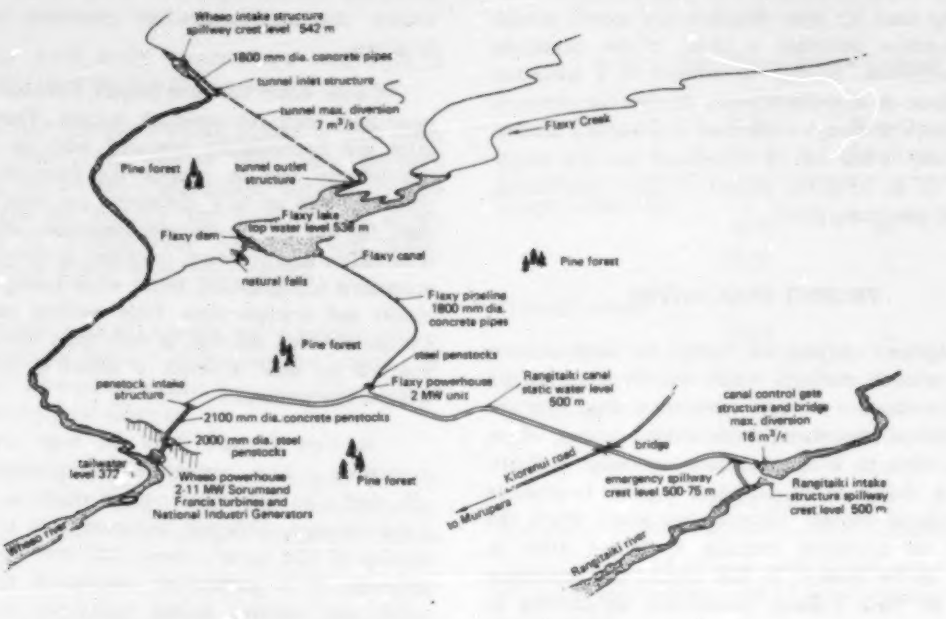
Wheao intake structure
spillway crest level 542 m
1800 mm dia. concrete pipes
tunnel inlet structure
tunnel max. diversion
7 m³/s
Flaxy Creek
Pine forest
tunnel outlet
structure
Flaxy lake
top water level 538 m
Flaxy dam
Flaxy canal
Pine forest
natural falls
Flaxy pipeline
1800 mm dia.
concrete pipes
Pine forest
steel penstocks
Flaxy powerhouse
2 MW unit
Rangitaiki canal
static water level
500 m
canal control gate
structure and bridge
max. diversion
16 m³/s
penstock intake
structure
2100 mm dia. concrete penstocks
2000 mm dia. steel
penstocks
tailwater
level 377
Wheao powerhouse
2-11 MW Sorumsand
Francis turbines and
National Industri Generators
Pine forest
Kiorenui road
bridge
emergency spillway
crest level 500·75 m
Rangitaiki intake
structure spillway
crest level 500 m
to Murupara
Wheao river
Rangitaiki river

Figure 1. General view of the Wheao project. The costs were kept down by building a canal of a simple structure and made with volcanic ash, a material freely available in the area.

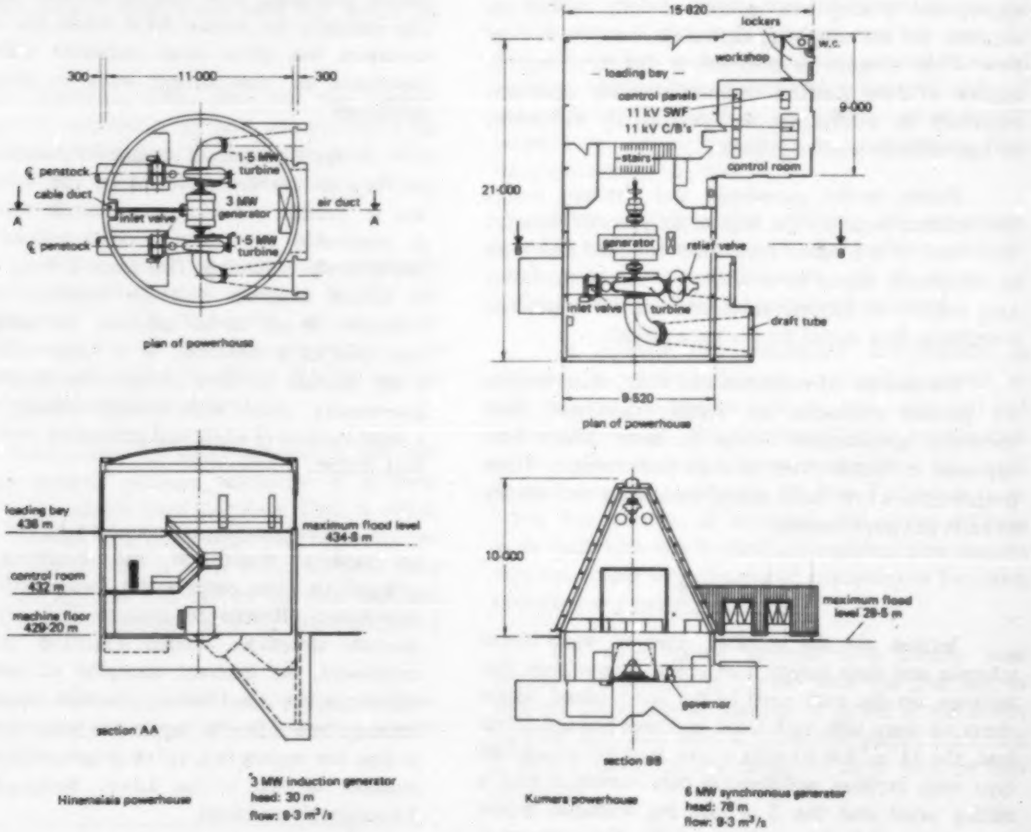
300
11 000
300
℄ penstock
cable duct
A
inlet valve
1·5 MW
turbine
3 MW
generator
air duct
A
℄ penstock
1·5 MW
turbine
plan of powerhouse
loading bay
438 m
maximum flood level
434·8 m
control room
432 m
machine floor
429·20 m
section AA
Hinemaiaia powerhouse
3 MW induction generator
head: 30 m
flow: 9·3 m³/s
15 820
lockers
w.c.
workshop
— loading bay —
control panels
11 kV SWF
11 kV C/B's
9 000
stairs
control room
21 000
B
generator
relief valve
B
inlet valve
turbine
draft tube
9 520
plan of powerhouse
10 000
maximum flood
level 28·5 m
governor
section BB
Kumara powerhouse
6 MW synchronous generator
head: 78 m
flow: 9·3 m³/s

Figure 2. Left, the Hinemaiaia powerplant, which incorporates a 3 MW induction generator, and operates under a head of 30m, with a flow rate of 9.3 m^3/sec. Right, the Kumara power plant, which incorporates a 6 MW synchronous generator, and operates under a head of 78m with a flow rate of 9.3 m^3/sec.

(tuff). Jointing is near vertical and widely spaced, and some relaxation of joints has occurred in the vicinity of the gorge. Weathering varies from unweathered or slightly weathered for the first 20 m about the river bed to moderately weathered at the spillway crest. The ratio of modulus of elasticity of concrete to the rock varies from 4 to 40.

Maximum height of dam about foundations is 33 m, with a crest length of 45 m. The spillway is a free overflow type 32 m long, discharging by stepped chutes on either bank into the gorge.

For ease of construction the dam is of a constant radius and thickness vertical axis type. A thickness of 2 m with flared abutments was adopted to provide a flexible structure to accept foundation movements under load and to minimize bearing stresses. Analysis was carried out using three-dimensional finite element techniques.

The dam is located on a bend in the river gorge so that foundations are asymmetrical. The choice of boundary conditions to be adopted in the computer model provided a difficult problem. Measurements of deflection made after impoundment, however, were reasonably close to those given by the computer and confirmed the adequacy of the assumptions made.

The right abutment required stitch-reinforcing across the rock jointing. Drains were provided in foundations and abutments after grouting.

Although topographically the site favoured an arch solution, rock properties were marginal. The more straightforward mass concrete option, however, would have added considerably to cost. Considerable engineering time and effort was expended in proving an arch design for a small scale job (total concrete volume 3000 m^3).

The use of available materials is also well illustrated by the 30 MW Patea project. This requires a 72 m-high embankment dam with a fill volume of 1×10^6 m^3, and a dam with silty clay core and gravel shoulders was originally considered. However, there proved to be insufficient material available locally in river terraces and it was decided to build a homogeneous embankment dam with a central chimney drain constructed from underlying tertiary sandstone deposits. This material, when excavated and recompacted, breaks down into a fine silty sand. The earthquake behaviour of a dam constructed of this material caused concern, since the site is in a seismically active area and there was no published data on behavioural patterns of similar dams. Following comprehensive laboratory testing, satisfactory behaviour of the material under dynamic loading has been established and the dam is now in the final design stages.

The use of available labour or contractor also influences materials used. In the Wheao river project the pipeline from the dam is a significant cost, and is being constructed from standard 2100 mm internal diameter spun reinforced concrete pipes as normally used for road culverts. Work has been divided between several local contractors, site establishment is kept to a minimum, and there is no temporary construction village. This greatly reduces the detrimental impact to the local community, whilst bringing economic benefits.

Original and economical solutions to powerhouse forms have been developed to enclose machines and provide flood rise protection in a aesthetically acceptable form. Hydro stations conventionally have machines arranged in a straight line with an overhead gantry crane. If horizontal machines are mounted on the centreline, there is no need for cross travel on the crane. An A-frame structure with a monorail hoist is then practical and substantially reduces the cost of lifting gear and power station superstructure (see figure 2). A-frame powerhouses were used in the Dillmans scheme on the South Island, which had a 6 MW and a 4 MW power station in series. Each station has a standard commercial monrail hoist and for heavy lift both hoists are used. Other stations rely on hired cranes for the installation and occasional maintenance of the heavy lift items.

At Taupo, North Island, a cylindrical powerhouse is being built with a diameter of 12 m and a height of 12 m. It houses a single machine consisting of a 3 MW generator in the centre of a shaft with a 1.5 MW Francis turbine under a 35-m head at each end (see figure 2). The powerhouse provides not only a most economical shape for excavation, but very good resistance to high flood pressures.

EQUIPMENT

There is a continuous debate over the merits of maintenance-free *versus* ease-of-maintenance for small hydro equipment. The first reduces the labour requirement and the servicing cost; the second requires personal visits and thus reduces the possibility of breakdowns etc., through lack of regular visual inspection. The second is preferred in New Zealand, where skilled labour is readily available in the supporting community, but the first has many advantages when building small schemes in neighbouring, underdeveloped countries. New Zealand itself is relatively isolated and spares and replacements are difficult to obtain quickly, thus leading to the development of more locally produced machinery and equipment suitable for use in New Zealand and neighbouring countries. New Zealand manufacturers are also becoming more willing to produce one-off orders at a reasonable cost, which will allow an even more flexible design approach by consultants to specific problems.

Where possible, induction generators are used with reactive compensation from extra capacity in associated synchronous machines or capacitor banks at the load centre. The majority of stations in New Zealand normally operate coupled to the network, but most are designed to operate on an isolated network to cover transmission line failure or maintenance. Low-cost diesel engine governor heads have been used, and at Auckland University, Professor Woodward has developed an electronic load shunting controller for micro-hydro sets which is presently undergoing trials in Papua New Guinea.

Mini turbines have been used to provide compensation water at the Aniwhenua powerhouse, where a 160 kW cross-flow turbine operates under a 8-m head feeding directly into the local network. It also drives hydraulic pumps for gate operation. At Mangapapa, a 20-kW Pelton turbine makes use of surplus energy in the cooling water for the generators and bearing oil, and at Wheao small water motors will be used for emergency oil supply to the generator bearings and governors.

All small stations need a reliable electrical protection system appropriate to the risks and value of the equipment. A system copied from a much larger station is too expensive and inappropriate.

With the high cost of labour, especially for shift workers, all small hydro stations up to 30 MW commissioned or being built in the last eight years operate on automatic or local automatic control. Stations are remotely controlled via radio or powerline carrier and there is a back-up system which will take over and keep the station running adequately in the event of communication link failure. Low cost, reliable industrial-type controls are used. Smaller stations are usually run on headwater control. Spillway and intake gates must also be automatic and are usually hydraulically operated with back-up power from pressure accumulators; but on some sites, self-operated, water-powered, radial spillway gates are used.

FUTURE DEVELOPMENTS

The potential exists for many more small schemes in New Zealand, but the present depressed state of the economy and a probable surplus of State generating capacity in the next decade will limit the number which will be officially approved. Without this approval finance becomes difficult, and this will generally preclude local authorities from construction. A recent estimate put New Zealand's underdeveloped generating potential from small schemes in the range 3000 to 4000 GWh/year, or some 100 schemes with power output up to 50 MW.

The domestic and political pressure to provide isolated rural communities with power was a major force in the establishment of small plants and it is precisely this pressure that is now becoming manifest in rural communities of New Zealand's developing neighbours, not necessarily to provide domestic power, since there can be some danger to uneducated consumers, but as a community service. With the ever-increasing cost of imported energy, use of an indigenous energy resource is becoming more necessary. Many other reasons are equally valid: import substitution, retention of population in rural areas, promotion of primary industrialization and increase of rural community resources.

R.E. Coxon's remarks in the *Water Power & Dam Construction* issue of August 1979 highlight the difficulties of financing large-scale hydro projects in developing countries, which will probably become less common. Additionally many developing countries can in fact make better use of a large number of smaller projects, for which finance is more readily available. Recent substantial increases in the cost of alternative energy sources also make small schemes more and more economical.

It is in integrated rural development projects that small schemes can play a very important role, not to provide a consumer service, as has been noted, but as a special service. For instance, power can be provided for water pumps to supply a reticulation system which substitutes for contaminated wells, thus increasing public health and the ability to work harder and longer on cash crops, or to power a local hospital or community/cottage industry. The expertise gained in New Zealand is already being applied in Fiji, Malaysia, Samoa and Solomon Islands. It is capable of much wider use.

POWER FOR VILLAGE PEOPLE IN THE SOLOMON ISLANDS*

Experience in developing a village-level hydroelectric power source in the South Pacific holds important lessons for developed countries such as Australia.

The tiny village of Iriri in Solomon Islands is soon to get a micro hydroelectric project designed at the New South Wales Institute of Technology. According to NSWIT lecturer in electrical engineering Dr. Paul Bryce, a prototype is operational and is expected to be installed in 1980 at a cost of $A 9,500.

The Solomon Islands project is a joint effort of interested engineers, technicians and craftsmen from electrical, mechanical and civil engineering schools. The experience suggests that villagers can be taught to construct, commission and maintain such a facility, says Dr. Bryce. In addition, it appears that small, village-based hydro developments of this nature, already common in Papua New Guinea, could similarly be used effectively on streams in remote parts of Australia.

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* In its original form this article was published under the title "Microhydro power for Solomons", in *Engineers Australia*, ISSN 0020-3319, vol. 51, No. 15 (27 July 1979), pp. 21-22. Copyright 1979 by Miadna Pty. Ltd. Reprinted with permission.

The project is supported by Appropriate Technology and Community Environment (APACE), an organization which is involved in the uses of renewable energy sources at the community level. An American company is funding construction and installation.

A village of only 130 people, Iriri is located on Kolombangara Island, about 100 km south-east of Bougainville and about 2000 km roughly north of Brisbane. Its only source of power at present is a diesel engine and some hurricane lamps. In order to get fuel, villagers have to travel 26 km by canoe and use up their very limited source of income to buy it. The village subsists on income received from selling excess produce from an organic farm. However, a woodworking shop has been built and a trial plot of cassava grown. The villagers hope eventually to use the cassava crop to produce ethyl alcohol and become self-sufficient in fuel.

Power from the micro hydroelectric project will be used for a sawbench, a four-sided moulder machine, tools for the farm and light for the houses. The micro hydroelectric system will be located on a mountain stream above a waterfall near the village. With an extinct volcano dominating the island landscape and 7500 mm of annual rainfall streaming down the mountain, micro hydroelectricity is the logical solution to provide energy.

TECHNICAL DESIGN

The electrical and mechanical design of transmission lines for the prototype turbine has been prepared and a variety of control and protection circuits investigated. A 7kVA alternator is coupled by V-belt pulleys to the turbine and has led to complete working drawings and specifications for an improved version.

At the heart of such a hydroelectric system is the turbine or water wheel. Turbine design depends on the head and volume flow rate of the water available. The 30 m head of water available at Iriri, although relatively low, has been found sufficient to drive an impulse turbine (Pelton wheel) to about 700 rev/min. Impulse turbines with small buckets that can react to a high-velocity water jet are used to take advantage of a high water head. Reaction turbines of large-blade area are generally employed where the volume flow rate is high. With the Kolombangara mountain streams offering neither characteristic, the Pelton wheel was the best compromise.

Water-deflecting buckets were made using a hardwood mandrel and conventional steel welding, which have not unduly affected their momentum-transferring task, according to project experience. Thrust bearings are of the self-centering type, thus avoiding the need for a special aligning jig or lathe bed. The final design will include provision for simple removal of these bearings during yearly maintenance inspections and lubrication.

Water is taken from the stream to the turbine through a double steel mesh filter, coupled to a 15 cm PVC drainpipe with a conical tube at the output end to replace the usual sophisticated needle shaft and nozzle. A relay-operated device between the tube outlet and the Pelton wheel buckets has been studied as a means to deflect the water in the event of a transmission-line failure. Such an event could otherwise cause over-revving followed by generator damage. This question is still being studied.

The Pelton wheel output is coupled to a 3-phase, 7 kW, self-excited, self-regulated alternator by V-belt mounted on pulleys designed to achieve 1500 rpm. The alternator output needs to be transmitted over 2 km of undulating country with many streams. An overhead line supported by cantilever brackets made of local hardwood has been recommended.

COST CONSIDERATIONS

The minimum cost recommendation for micro hydroelectricity at Iriri involves a 415 V-3300 V step-up transformer at the generator, with a 3-phase line feeding a 3300V-415V transformer at the village. A distribution panel will be installed in the village to allow either a 3-phase 415 V or single-phase 240 V for domestic use. To avoid load fluctuations at the alternator, a dummy load will consume the excess transmission power at all times.

A new type of field-effect-transistor/light-emitting-diode combination may be used in a simple circuit to automatically control the changeover of power from dummy load to user outlets when village electrical devices are operated. An interesting feature of the design is the lack of dashpots, levers, governors or other forms of hydraulically or mechanically operated control systems at the turbine.

"Although tests are still continuing, it may well prove to be a cheaper, more reliable and more simply maintained system that relies almost solely on solid-state electronic control", says Dr. Bryce, adding that Australia's experience in such a project as this may well change national thinking about the potential and the effective use of even the most humble streams that flow freely in the countryside.

INFORMATION CHANNELS

Selected news and information on water resources developments of interest to programmes in the Asian-Pacific region

Briefs

Biggest fresh-water scheme in the world's biggest ocean

The Nadi-Lautoka water supply scheme, Fiji, is now under construction by the Hornibrook-Thiess-Leighton joint venture of Australia.

The $US 59 million scheme is one of the largest to be carried out in the Pacific basin and is supported by the biggest loan made to date for an individual contract by the Export Finance and Insurance Corporation (EFIC). EFIC is funding $A 34 million of the contract price, and the balance is being made available through merchant banks.

The western coastline of Fiji's main island, Viti Levu, known as the "dry side", has always suffered from a lack of water. Supplies to the main towns, Nadi and Lautoka, in the past have been cut off for hours at a time because of severe drought, and the country's major industries, tourism and sugar-cane production have been affected to such an extent that the Government placed an embargo on the building of hotels.

The project can be split into three main parts: the water reticulation system; water treatment plant and main supply; and a 35 m-high dam.

Construction will be planned around the seasons so that the required densities of the materials used in the building of the dam can be achieved.

The dam will be sited in the neighbouring highlands, about 40 km from the coastal strip. Built at an elevation of 1000 m, it will require more than 1×10^6 m^3 of local earth and rockfill, which will be obtained from the spillway excavations.

More than 600 m^3 of reinforced concrete will be used for the water treatment works, and 700 m of diversion and supply tunnels will be associated with the dam and spillway.

A total of 60 km of pipeline will be laid. The first job is the excavation of about 600,000 m^3 of material to provide an access road to the pipeline route.

It has been estimated that a labour force of about 350 (300 local residents and up to 50 Australians) will be required for the project.

– From *Water Power & Dam Construction*, December 1980, pp. 8, 43.

China's first tidal plant to double capacity

China's first tidal power station, which came on stream in May 1980 with a 500 kW bulb turbine, is to be doubled in size this year. It is located in Zhejiang province near the mouth of the shallow Jiangxia Creek, which runs into Yueqing Bay, East China Sea.

The $US 4.1 million plant operates on both the ebb and flow tides and is expected to have six 500 kW sets ultimately. The existing turbine operates for 15 hours a day and feeds a small processing plant 20 km away.

An earth and stone dam 600 m long and 15.5 m high spans the creek and contains a 2.75 km^2 tidal lake. Fish and prawns are raised in the lake and potash is extracted from it for fertilizer.

The tide in the creek rises to a maximum height of 8.39 m twice a day with a five to seven hour interval. The turbine has a 2.5 m diameter runner and weighs 86.7 tons.

The station serves as an experimental centre for the construction of more and bigger tidal plants and is some 100 m away from a 40 kW ebb-flow-only experimental plant completed in 1959.

Chinese engineers have estimated their country's tidal power potential to be 110,000 MW, or one-tenth of the world's total, at 500 or more sites along the country's seven coastal provinces of Zhejiang, Fujian, Shandong, Guangdong, Jiangsu, Hebei and Liaoning. They believe at least 35,000 MW of this could be exploited in the foreseeable future.

Although the Jiangxia station is much smaller than the 240 MW station on the Rance in Brittany, which has been operational since 1966, it is slightly larger than the only other sizeable operational tidal station, the 400 kW unit which has been functioning at Kislayaguba near Murmansk in the Soviet Arctic for the last 12 years.

– From *Water Power and Dam Construction*, February 1981, p. 3.

Land use and catchment capability in Australia

Changes in farmland use in south-eastern New South Wales, Australia, are important considerations in planning for a continuing water supply for Sydney.

A team from the Central Scientific Information and Research Organization (CSIRO) division of plant industry in Canberra recently completed a six-year study on the Shoalhaven River area to gauge likely consequences of land-use changes on stream and river flows.

The land under study forms part of a scheme which will enable water from the Shoalhaven to nearly double Sydney's water supply.

The Shoalhaven River catchment is particularly significant because, unlike most other urban catchment areas, it is not exclusively reserved for its water supply function, said Dr. A. Aston, study group leader.

The team found an increasing trend toward clearing native forests for either pine plantations or improved grazing pastures.

It built a mathematical model which took into account each process in the hydrological cycle: soil types, vegetation usage, amounts of water lost in evaporation, types of plants and their relative water requirements.

To check the accuracy of the model, the team tested it in detail against a small area in the upper Shoalhaven Valley, where similar hydrological data had already been gathered.

"Generally, we found that streamflow could be reduced by up to 28 per cent when pasture improvement had taken place", Aston said.

"Conversion of native pasture to pine plantation intercepts more water and evaporates more water–up to 33 per cent in an average year".

– From *Engineers Australia*, vol. 52, No. 13 (27 June - 10 July 1980), p. 18.

IDA credit for new irrigation scheme in India

The International Development Association (IDA), an affiliate of the World Bank, has announced the approval of a credit of SDR 63.3 million (equivalent to approx. $US 83 million) to help finance an irrigation project in the State of Orissa in India.

The $ 110.3 million project will help ensure a continuous supply of irrigation water in a 167,000-ha command area now served by two weirs which are 110 years old and need to be replaced. The project will safeguard farm income and employment, and includes the development of a drainage master plan for the entire Mahanadi Delta and a programme of water management.

The IDA credit to India is for 50 years, including a ten-year grace period. It is interest-free, except for a service charge of 0.75 per cent to meet IDA's administrative costs.

– From *Water Power & Dam Construction*, February 1981.

Water plants to clean up wastewater

The world's first municipal wastewater treatment plant to use water hyacinths for secondary treatment has been started up at Hercules, California. The facility is expected to require about a third of the energy and half of the maintenance of a conventional plant. Water treated by the 350,000-gpd plant is of tertiary-treated quality and will be used for irrigation or sold to industry as a coolant. The hyacinths will be harvested and sold as a soil enhancer.

In the plant, designed by Solar Aquasystems, Inc. of Encinitas, California, primary treatment is accomplished anaerobically to break down greases and allow grit to settle out. Sewage is then sent to a hyacinth pond where nutrients are absorbed, including heavy metals and petroleum hydrocarbons. Retention time is about six days, compared to two to three for a conventional plant. The system is enclosed in a greenhouse to prevent damage to the hyacinths from a killing frost.

– From *Water Newsletter*, vol. 22, No. 11 (13 June 1980).

An automated irrigation system for China

The first automated irrigation project utilizing Zimmatic Lateral Move irrigation systems, and the first project of its type to be developed at the commune farm level, is now in full operation in the People's Republic of China, near Shrjiaz-huang City, Hebei Province, 200 km south of Beijing.

The new project, located at Cheng Lang experimental station, involves two Lateral Move irrigation systems, the most advanced and recent development in automated irrigation. The Lindsay Lateral Move system, introduced in the United States over three years ago, has been developed by the Lindsay Manufacturing Company of Lindsay, Nebraska. Each Lateral Move machine is 800 m long and travels 3.3 km. The two systems together irrigate a total of 518 ha.

Prior to installation of the Lateral Move systems, the area was flood-irrigated. It is anticipated that water savings in the range of 40 to 50 per cent will be achieved as a result of this technology. Water conservation was a major factor in the decision by Chinese authorities to implement the project. Where small fields existed, two large individual fields growing one specific crop each season will be used. From October to June each year, winter wheat will be grown; and from June to October, field corn.

Installation and erection of the systems by Chinese workers under supervision of Lindsay technicians started early in September 1979 and were completed by 10 October, in time for the planting of winter wheat. The Lateral Move concept involves an automated, laterally moving pipeline supported by travelling towers. Water is supplied to the system through a ditch, and distributed to the soil through spray nozzles located along the length of the pipeline.

– From *Water Services*, vol. 84, No. 1010 (April 1980), p. 229.

Pune laboratory studies India's hydro problems

More than 450 research projects are being studied at the research laboratory of India's Central Water and Power Authority, located about 180 km south-east of Bombay. In addition to tackling problems of coastal engineering, thermal station cooling and instrumentation, the laboratory, with the aid of more than 200 models, investigates pumps and turbine operation, cavitation and silt dispersal. Turbine and pump models are checked for efficiency and for cavitation according to international test codes; the laboratory system can provide a head of 22 m in series operation, and a flow of 3000 l/sec in parallel formation. For pump tests, the tunnel circuit can be hydraulically and electrically reversed.

Field studies cover earthquake problems (a number of major papers have been published on the Koyna earthquake), prototype testing and effluent dispersal.

Tidal power is one of the subjects being examined at the laboratories, and a preliminary analysis of costs and physical details has been assembled. Four sites at the Gulf of Kutch have been examined; a tidal range from a minimum of 3.0 m to a maximum of 7.1 m has been recorded at one site which could have an annual energy output of up to 3037 GWh.

Among the dam projects being studied is the Trisuli barrage in Nepal, for which a large model has been built. Silt disposal, as in most such projects on the South Asian subcontinent, poses some problems, and a flushing system has been devised which appears to offer an effective solution without adding greatly to civil costs.

Problems with the Ramganga dam trashrack which were described at the Thirteenth ICOLD Congress (see *Water Power & Dam Construction*, January 1980) have been investigated and eventually solved with models and studies carried out at Pune. The trashrack, weighing 8 t, had been thrown out of position during low-level operation of the reservoir, and the model revealed that air, trapped under certain conditions of flow, was responsible.

Structural engineering aspects, of particular relevance to hydro projects which involve underground elements such as tunnels and long water conduits, are examined with the aid of two- and three-dimensional photoelastic techniques. Structural models made of plastic materials, microconcrete, metals, gelatine, plaster of Paris etc. are used for stress analysis. Where necessary, model results are supplemented by analytical methods and prototype studies. A 200-channel data logger is available for experimental stress analysis.

ESCAP has recognized the organization as a regional laboratory to serve the needs of the ESCAP region, with particular reference to the development of ports, estuaries and inland waterways.

– From *Water Power & Dam Construction*, February 1981, p. 50.

Radio-isotope dating of Australia's ancient underground water

Scientists at the Australian atomic energy establishment are measuring the radioactivity of natural isotopes in underground water to determine its age. This radio-isotope dating has led to new knowledge of Australia's Great Artesian Basin. The intake beds for this vast underground storage site are situated on the western slopes of mountains in north-eastern Australia. By dating water from the bores at progressively greater distances from the intake area, scientists have found that the water filters slowly south-west towards south Australia at the rate of about 1 m per year. This means that water from bores in the deepest part of the Great Artesian Basin is about 500,000 years old. Nobody knows the capacity of the Great Artesian Basin, but the water is certainly hundreds of thousands of years old and the question facing Australian farmers and ranchers is whether it is being replenished rapidly enough to compensate for the loss from artesian bores, many of which have been tapped for a century or more.

If the radio-isotope dating shows that water from a bore is only a few years old, then it is being replenished quite frequently by rains or from a river source. If, however, the water turns out to be many thousands of years old, then it is clearly not being replenished. It may be that the source tapped will last many centuries, but the fact remains that the farmer is, in effect, "mining" and not "farming" this vital resource. Country people in Australia are all too familiar with the devastation of droughts which afflict this arid continent. Because of the unreliable rainfall, rural Australians are more dependent upon ground water than farmers in most other countries. For them it is a matter of practical importance whether ground water is being replenished, and the scientists at the atomic research establishment have already made some discoveries about the age of Australian ground water which have been of practical value to Australian farmers.

Cotton growers in the Namoi district of New South Wales irrigate their crops from bores which they believed were continually being replenished by rainfall and seepage from a nearby river. Worried by reports that an impending drought would prevent the replenishment of their ground water, they sent samples to the scientists. Some water proved to be tens of thousands of years old and obviously had no connection with present rainfall or river seepage. The scientists in fact concluded from the evidence that some water was seeping in from the much larger and deeper Great Artesian Basin nearby, and that supplies of ground water for the cotton growers will not be affected by individual droughts.

This technique has also been applied to one of Australia's greatest tourist attractions, Ayers Rock. This is reputed to be the world's largest single rock, about 335 m high and about 8 km in circumference. Each year it attracts tens of thousands of local and overseas tourists. Probably Australia's number one tourist attraction, it is situated in desert country in the Northern Territory and its water supplies come from bores.

However, with a greatly increased influx of tourists, the water supply has become something of a problem, and the tourist authorities considered using a spring which they believed was being renewed every few years by rainfall. The scientists measured the isotope carbon-14 in the water and found it to be thousands of years old, proving the spring to be a finite source which was not being replenished. Now at least the tourist authorities know they are "mining" their water resources at Ayers Rock, and can plan accordingly.

Recent warnings by Australian ecologists suggest a certain urgency about the appraisal of Australian ground-water resources. At an international conference on desertification the delegates were told that Australia could become the world's biggest dust bowl as a result of bad farming techniques. They were also told that, because of soil and climatic changes, much of Australia's farming and grazing land needs about twice as much rain as at the start of the century to be as productive. Should this forecast prove correct, the scientific appraisal of Australia's ground-water resources will be of prime national importance.

– From *Water Services*, vol. 84, No. 1016 (October 1980), p. 618.

Drinking water/water pollution role for United Kingdom Water Research Centre

The Water Research Centre in the United Kingdom has become the WHO Collaborating Centre for drinking water and water pollution control for the WHO Regional Office for Europe in Copenhagen.

The agreement which initiated this collaboration for a period of three years was signed on 23 June 1980 in Copenhagen by Dr. Leo A Kaprio, WHO regional director for Europe, Mr. R.T. Whiteley, chairman of the Council of WRC and Mr. J.L. van der Post, WRC chief executive.

In welcoming the agreement, Dr. Kaprio stated that it represented a major step forward in the development of the environmental health programme of the WHO European office. Although a high proportion of countries within the region had adequate supplies of water, a wide range of problems concerning chemical toxicity were of concern to European Governments. The collaborative arrangement with WRC was of particular importance in relation to the chemical safety programme adopted by the regional committee in Helsinki in September 1979.

The agreement provides that WRC will undertake work in areas of special interest to the WHO Regional Office for Europe. The following subjects are of special interest: drinking water quality, water treatment, ground-water pollution, tidal waters quality management and sampling and analysis of waters. Of these, the highest priority will be given to the health aspects of drinking water quality. On behalf of the regional office, WRC will also prepare a survey of the administrative structure of European water services, and will provide the office with access to information systems such as "AQUALINE" and the data-base of "INSTAB".

This is the first agreement of such magnitude concluded with a European research centre and is considered by WHO to be of particular significance in view of the launching later this year of the International Drinking Water Supply and Sanitation Decade.

– From *Water Services*, vol. 84, No. 1013 (July 1980), p. 401.

ASIA/PACIFIC REGION

ADB lending for water projects

Development of water resources claimed a significant share of the loans meted out by the Asian Development Bank (ADB) during 1980. Details of ADB loans and technical assistance approved in 1980, pertaining to water resources in Asian and Pacific countries, are reproduced below in brief form as published in the *Asian Development Bank Annual Report 1980.* Water resources development is taken here to include water supply, some agricultural uses (such as irrigation and aquaculture inputs), hydropower and hydroelectric schemes, and such urban development aspects as sewage treatment.

Note: Loans are made from ordinary capital resources unless otherwise specified, and include technical assistance loans. Technical assistance refers to that provided on a grant basis.)

Bangladesh

Loans

Tubewells. $US 50 million from the Asian Development Fund (ADF) for the installation of 960 deep tubewells and command area development, agricultural support services, provision of equipment and facilities for operation, maintenance and ground-water monitoring, and consultant services in the Dinajpur district of extreme north-western Bangladesh. This will enhance foodgrain production through the year-round cropping of about 44,000 ha of irrigable land, benefiting about 22,000 farm families and generating substantial new employment opportunities.

Technical assistance

Small-scale irrigation sector. $450,000 (to be financed by the Government of Switzerland with ADB acting as administrator) for a study of potentials in the small-scale irrigation sector, a detailed feasibility study of five selected, core, small-scale projects totalling some 10,000 ha, formulation of a sector project and establishment of guidelines, procedures and criteria for use by the executing agency.

Burma

Technical assistance

Yenwe multipurpose. $370,000 (to be financed by UNDP with ADB acting as executing agency) for upgrading an earlier feasibility study for a project aimed at enhancing agricultural production, rural employment opportunities and farm incomes, as well as supplementing Burma's hydropower generation capability.

Mini-hydropower. $220,000 for a feasibility study of 10 mini-hydropower schemes, ranging in capacity from 300 kW to 4000 kW, which will provide a reliable power supply to remote areas of the country which are presently served by outdated diesel generators.

Cook Islands

Loans

Multiproject loan. $1 million from ADF, the Bank's first loan to the Cook Islands, to finance a package of small subprojects in the public sector. These subprojects are expected to relate to construction of a drainage and flood control system, a new packing shed, a new wharf and health centres; rehabilitation of a wharf; and improvement of about 25 km of plantation roads.

Technical assistance

Appraisal of subprojects under multiproject loan. $70,000 to finance consultant services for the preparation and appraisal of subprojects.

Indonesia

Loans

Sumatra fisheries development. $14 million for a project to increase fish production for local consumption and export. The project also includes provision of credit through the Bank Rakyat Indonesia to individual fishermen and fish farmers (see technical assistance which follows). The project has a marine component and an aquaculture component. The project is expected to benefit about 6000 small-scale fishermen and fish farmers in four less-developed provinces of Sumatra and to generate annual net foreign exchange earnings of approximately $5 million.

Cibaliung irrigation. $35 million for a project designed to raise paddy and soybean production significantly over a 13,000 ha area of far-western Java, one of the lesser-developed regions of the country. Besides irrigation, soil conservation and village water supply, the project also includes a staff training and development programme. At completion, the project is expected to benefit some 18,000 rural families, contribute to Indonesia's programme for self-sufficiency in food and raise local farm incomes; and during construction, to generate around 23,000 man-years of new employment opportunities.

Lower Citanduy irrigation. $55.2 million for an integrated development project which, by providing assured irrigation water to 24,200 ha, will raise paddy and soybean production in an impoverished region of central Java. About 53,000 farm families will benefit, with their annual incomes expected to increase from about $160 to almost $500. In addition, some 5200 sharecropping farm families will become owners of farm land. The European Economic Community (EEC) has agreed to provide co-financing amounting to $4.9 million. This loan is the largest made so far by ADB for irrigation.

Northern Sumatra irrigation study. $5.7 million as a technical assistance loan to finance consultant services for upgrading existing studies of two areas in north Sumatra and Aceh provinces to full feasibility level for possible external financing (see technical assistance which follows).

Small towns water supply sector. $32 million for a project designed to provide cost-effective water supply schemes to about 33 small towns in the provinces of central Java and south Sumatra, with the population of the majority of towns ranging from 15,000 to 60,000 people. The project, which is expected to benefit a total of approximately 720,000 people, is in line with the Government's programme to provide potable water to small and medium-sized towns. This is ADB's first sector loan.

Technical assistance

Water supply sector. $100,000 for a feasibility study of the Small Towns Water Supply Sector Project which subsequently resulted in an ADB loan.

Sumatra fisheries development. $200,000 (to be financed by the Government of Switzerland with ADB acting as administrator) for the services of an adviser who will assist in the implementation of the project.

Northern Sumatra irrigation study. $150,000 to finance part of the foreign exchange costs of the project.

Lao People's Democratic Republic

Loans

Vientiane plain rural electrification. $4.3 million from ADF to boost food production through pump irrigation schemes, permit the development of agriculture-based and other industries, and raise the living standards of the rural population through greater use of electricity produced by the Nam Ngum hydropower station. This project will involve the electrification of 76 villages.

Technical assistance

Xeset hydropower. $246,000 for consultant services to investigate the feasibility of a hydropower station at a site on the Xeset River in the southern region of the country and prepare a project which will include a hydropower station and the associated transmission lines and distribution system.

Malaysia

Loans

Kemasin rural development. $40 million for a project designed to improve the socio-economic condition of small farmers through the provision of flood mitigation, irrigation and drainage facilities, and the strengthening of agricultural support services. More than 12,700 small-holder farming families in the east coast State of Kelantan will benefit directly from the project. Upon project completion, the annual family income of an average 1.8-ha farm is projected to increase from $470 to $1880.

Rural water supply master plan. $2.81 million as a technical assistance loan to finance consultant services to prepare a master plan covering all 13 States of Malaysia for the development of an adequate and safe water supply for the rural population by 1990 (see technical assistance which follows).

Technical assistance

Rural water supply master plan. $150,000 to finance part of the foreign exchange costs of consultant services to prepare the master plan.

Nepal

Loans

Aquaculture development. $11.8 million from ADF for a project designed to bring higher levels of animal protein into the country's national diet and increase employment opportunities. The project includes provision of credit to 8000 fish farmers and marketers through the Agricultural Development Bank of Nepal (see technical assistance which follows).

Hill irrigation (western region). $11.7 million from ADF for a project which includes the construction of and improvements to irrigation systems, strengthening of agricultural support services, rural training in crop husbandry techniques and water management, storage and marketing facilities, and enhancement of the role of co-operatives and supply of agricultural inputs. About 21,000 people are expected to benefit from these developments (see technical assistance which follows).

Technical assistance

Aquaculture development. $1,670,000 (including $1,370,000 to be financed by UNDP with ADB acting as executing agency) for a fellowship programme and consultant services.

Command area development. $350,000 (to be financed by UNDP with ADB acting as executing agency) for a feasibility study of four existing irrigation schemes, centred on command area development and water management, in the Terai area of the central and western development regions in southern Nepal.

Hill irrigation. $900,000 (to be financed by UNDP with ADB acting as executing agency) for project implementation and for institution-building and overseas training of Government staff.

Second hill irrigation. $530,000 (to be financed by UNDP, with ADB acting as executing agency) to cover the preparation of a possible sector feasibility study for a project in the Seti zone, covering in detail an aggregate area of about 5000 ha.

Pakistan

Loans

On-farm water management. $25 million from ADF for a project designed to increase agricultural production through water-course reconstruction, complementary ground-water supply and improved on-farm water management. About 43,000 farm families will benefit and annual foreign exchange savings of about $26 million will be achieved through increased wheat production.

Technical assistance

On-farm water management. $132,000 for a study designed to improve the availability of irrigation water through improvements to water courses, supply of shallow tubewells and on-farm water management in North-west Frontier and Punjab Provinces.

Philippines

Loans

Second Laguna de Bay irrigation. $20 million from ADF for a pioneering project which emphasizes intensive vegetable cultivation along with rice. The net annual incremental productions of paddy and vegetables will be about 55,000 and 50,000 metric tons, respectively, which will generate net incremental benefits of about $13 million and will directly benefit some 5800 farm families. The OPEC Fund for International Development is providing $7.5 million in co-financing for this project.

Manila sewerage. $42.8 million for a project aimed at providing improved sewerage and sanitation services to about 3.2 million people in the Manila area. The project is the first stage of a long-term sewerage and sanitation master plan for Metro Manila. The World Bank is providing a loan of $63 million for co-financing this project.

Republic of Korea

Loans

Samrangjin pumped storage power. $52.63 million for a project which will help meet projected increases in demand for electricity and help the Government reduce its dependence on oil imports and diversify energy supply sources. It will provide 600 MW peaking/reserve capacity from 1984 to the Korea Electric Company power system. Co-financing with commercial banks amounting to $11 million was arranged for the project.

Sewage treatement. $27.9 million for a project which forms the first stage of a sewerage programme up to the year 2000 to provide sewage treatment and sanitation systems in the cities of Gumi and Banweol, serving populations of 260,000 and 225,000, respectively.

Technical assistance

Han River basin environmental master plan. $125,000 for assistance in institution-building of the Office of Environment under the Ministry of Health and Social Affairs and the preparation of terms of reference for consultants to prepare a Han River basin environmental master plan.

Samoa

Technical assistance

Fagaloa/Afulilo hydropower scheme. $348,000 for consultant services to determine the optimum development of the potential of the Vaipu/Afulilo basins and to examine the technical feasibility and economic viability of constructing the Fagaloa/Afulilo Scheme as a storage scheme.

Solomon Islands

Loans

Honiara water supply. $1.65 million from ADF to finance the development of two springs to meet the rapidly increasing water demand in Honiara up to 1995.

Thailand

Technical assistance

Medium-scale irrigation package. $350,000 (to be financed by EEC with ADB acting as executing agency) for a feasibility study for a project aimed at improving agricultural productivity and raising farmers' incomes in five subproject areas in the northern, central and eastern regions of the country.

Sources

New information sources available in the water resources field

Online

United Kingdom water data base: AQUALINE. The AQUALINE data base is available in Australia on the US Lockheed Information System, DIALOG. AQUALINE is the data base produced by the Water Research Centre, England. It includes abstracted literature from the world's scientific and technical publications on every aspect of water, wastewater and the aquatic environment. The main subject coverage is listed as follows: water resource development and management; drinking water quality; water treatment; distribution systems; tidal waters, quality monitoring, sampling and analysis of water and wastes; and environmental protection.

All of the material from the printed abstract journal, *WRC Information*, is in the file, together with additional references. Articles selected from over 400 periodicals are included, as well as research reports, legislation, conference proceedings and pre-prints, books and monographs, pamphlets, dissertations, translations, standards, specifications and other publications from water-related institutions world-wide. The file contains 22,350 records covering the period 1974 to January 1981. It has been estimated that about 4500 records will be added each year.

AQUALINE has published a thesaurus of terms under which topics may be traced. The thesaurus is the most exhaustive dictionary compilation of all the currently used words and phrases in the world's water literature and lists all terms required to search the AQUALINE computer file of abstracts. Comprising over 70,000 index terms, the book indicates the relationship between words, suggesting alternative words, phrases and expressions to allow fast and economic information retrieval.

AGE data-based update. The Asian Information Center for Geotechnical Engineering (AGE), located at the Asian Institute of Technology at Bangkok, Thailand, has built up a computerized data base over the past eight years which currently boasts over 20,000 bibliographic items. Early in 1980 AGE converted its holdings into the Integrated Science Information Service (ISIS) format, obtained from UNESCO, which is being used in over 20 other data bases around the world. All future editions of *AGE Digest* and of *AGE Abstracts* will be produced using the ISIS system, and consequently *AGE Abstracts* will also be available online. This new system is available for online searching, data entry and retrieval. Searches of bibliographic records and abstracts may be done on the basis of keyword, geographical keyword, International Geological Congress classification, author, language and year of publication.

The new system is also used by other information centers at the Asian Institute of Technology, namely the Environmental Sanitation Information Center and the International Ferrocement Information Center.

Having received some requests for acquiring the data base on magnetic tapes, AGE is in the process of determining the costs involved and fixing a reasonable selling price.

Funding agencies merge consultant registers. The World Bank and the Inter-American Development Bank are combining their registers of consulting engineers in a computer-based system entitled DACON (data on consultants). The system will also be used by UNDP, and the DACON registration form will be accepted by the United Nations Industrial Development Organization (UNIDO), ILO, WHO, the Asian Development Bank, the Arab Fund for Economic Development in Africa and the Kuwait and Abu Dhabi Fund for Arab Economic Development.

Computer programmes in hydraulics. As one of its duties, the Task Committee on Computational Hydraulics of the Hydraulics Division, ASCE, has compiled a list of bibliographies and publications that list the availability of various mathematical, numerical and computer models for general use by hydraulic engineers. The compilation covers several major areas, such as hydraulics, hydrology, ground water, surface water, water-resources management, unsteady flow, estuaries and so forth. Most of the entries are described by essential information, such as authors(s), editor(s) or personnel to contact, year of publication or compilation, title, publishing journal or issuing organization, number of pages, number of references, programmes or models listed, author affiliation, project sponsor and notes that summarize any other pertinent and helpful information. It is hoped that the material included in the list will aid potential model users in finding suitable bibliographies, contacting key personnel and accessing appropriate computing facilities. For full reference, see "Sources of computer programmes in hydraulics", *Journal of the Hydraulics Division*, ASCE, vol. 106, No. HY5, proc. paper 15435 (May 1980), pp. 915-922.

First issues

International Water Report launched its first quarterly number, Summer 1980, under the editorship of Judith M. Corcoran. Designed for a North American readership, the new newsletter offers a broad sampling of current developments in the international water field. A comprehensive range of material from each continent is compiled every quarter to provide subscribers with recent news in water development, supply and treatment; treaties and legislation affecting the global community; and water-related incidents throughout the world. Further information about the newsletter can be obtained from the publisher: Water Information Center, Inc., The North Shore Atrium, 6800 Jericho Turnpike, Syosset, New York 11791, United States.

Ground Water Heat Pump Journal has issued its first quarterly number, Spring 1980. Published by the Water Well Journal Publishing Company (500 West Wilson Bridge Road, Suite 130, Worthington, Ohio 43085, United States), this recent addition to periodicals in the water field is edited by Jay H. Lehr and is available to subscribers outside North America for $US 15.- per year.

Another new entry published by the Water Well Publishing Company is the *Ground Water Monitoring Review*, which has set itself the task of covering all facets of ground-water monitoring, including literature and equipment reviews, and legislative and regulatory updates. Upcoming articles will be concerned with ground-water monitoring to determine hydrologic consequences of mining and reclamation operations; State requirements for monitoring ground-water quality of waste disposal sites; preserving samples drawn from monitor wells; monitoring for hazardous constituents in ground water; and a model State programme for enforcement of the underground injection control programme. The journal, edited by Robin McGuire, scheduled its first issue to appear in Spring 1981. Subscriptions are available for $US 16 a year from *Ground-Water Monitoring Review*, 500 West Wilson Bridge Road, Suite 130, Worthington, Ohio 43085, United States.

Soil and Water Conservation News is the title of the new official newsmagazine of the United States Soil Conservation Service, and replaces the *Soil Conservation* magazine published by the Service for nearly 45 years. With its first issue in April 1980, *Soil and Water Conservation News* announced its aim to report as many of the significant conservation stories as possible: in research, new conservation techniques, programmes, ideas for administrative improvement, meetings and other forums, and action taken under the United States Soil and Water Resources Conservation Act of 1977. Content is limited in coverage to soil conservation in the United States, Puerto Rico and the Virgin Islands. Judith E. Ladd is the editor. (Contact address: Information Division, Soil Conservation Service, United States Department of Agriculture, Washington, D.C. 20013.)

Information center

The Water and Sanitation for Health (WASH) Project has been established by the United States Agency for International Development (USAID) in support of the objectives of the International Drinking Water Supply and Sanitation Decade, 1981-1990. WASH will provide assistance in terms of information support, among other categories, to USAID missions, USAID regional bureaux and central offices, and through them, to other international agencies, host country governments, private voluntary organizations and other United States agencies and private organizations in the AID developing countries.

The WASH Co-ordination and Information Center will establish a clearing house information retrieval facility, and provide: (a) searching, collection, synthesis, reproduction, and dissemination services to missions or bureaux requesting special information; (b) co-ordination/information services to interface with the United Nations and other bilateral donor systems; and (c) a variety of related services.

Water Calendar

1981

26 August - 7 September	Grenoble, France	Eleventh ICID Congress on Irrigation and Drainage will comprise two technical meetings, on "The improvement and modernization of existing irrigation and drainage systems" and on "Flood control in relation to land utilization planning and to the management of water resources"; a special session on "The evaluation of completed projects"; and a symposium on "Design principles for water and irrigation control systems applying modern technology". Address enquiries to ICID, Avenue d'Innsbruck, 38029 Grenoble Cedex, France.
1-4 September	Uppsala, Sweden	Salt Water Intrusion Meeting. Contact: Mrs. M. Falkenmark, Executive Secretary of the Committee for Hydrology, Wenner-Gren Center, Sveavägen 166/15, S-1113 46 Stockholm, Sweden.
2-4 September	Wembley, England	Second International Environment and Safety Conference and Exhibition, to be held at the Wembley Conference Centre, will bring together environmentalists, hygienists and safety specialists. The conference comprises three principal discussions, on: water (waste, recycling); gas, dust, air; safety in a working environment. The theme of the accompanying exhibition is "Occupational health and hygiene and environmental safety". Contact: The Organisers, International Environment and Safety Exhibition and Conference, Newgate, Sandpit Lane, St Albans, Herts AL4 0BS, England.
7-11 September	Lisbon, Portugal	United Nations Symposium on Water Resources Management in Industrial Areas will be held at the Galouste Gulbenkian Foundation, Lisbon, sponsored by the United Nations and the Portuguese Government, UNIDO, UNEP and the International Water Resources Association. For information contact Mr. L. Veiga da Cunha, International Symposium on WRMIA, APRH, c/o LNEC, Av. do Brasil 101, 1799 Lisbon, Portugal.
14-17 September	Tel Aviv, Israel	"Agritech '81", an international symposium and exhibition on agricultural and irrigation equipment, will include "New methods in remote-controlled irrigation" among its discussion topics. Daily demonstrations of machinery and equipment, meetings with specialists and visits to Israeli farm systems are planned. Contact: Organizing Committee, Agritech '81, POB 29732, Tel Aviv 61028, Israel.
21-25 September	Cambridge, England	An international fluvial conference on the theme "Modern and ancient fluvial systems: sedimentology and processes" is expected to draw engineers, geomorphologists and geologists engaged in research into all aspects of river sedimentation. Information is available from the International Fluvial Conference, Department of Geology, University of Keele, Keele, Staffordshire, England.
23-25 September	Cambridge, England	Second International Symposium on Wave and Tidal Energy, sponsored by the British Hydromechanics Research Association (BHRA) Fluid Engineering, will offer progress reports from individual countries on tidal power studies. Other topics to be addressed are estuarial geometry; characteristics of waves and tides; equipment (buoys, pumps and turbines); construction and operational problems; ocean currents and thermal energy; and applications and comparisons with conventional energy sources. Contact: Symposium Organizer, Second WTE, BHRA Fluid Engineering, Cranfield, Bedford MK43 0AJ, England.

24-25 September	Loughborough, Leicestershire, England	Seventh WEDC Conference focuses on water, people and waste in developing countries. For further details of the conference and other WEDC activities, contact: John Pickford, WEDC, Department of Civil Engineering, University of Technology, Loughborough, Leicestershire LE11 3TU, England. (A conference on waste and waste engineering in Asia is planned to be held in Madras, India in 1982.)
26 September - 3 October	Berne, Switzerland	International Symposium on Tracer Techniques in Hydrology. Contact: Geographisches Institut, 4. SUWT, Dr. Ch. Leibundgut, Hallerstr. 12, CH-3012 Berne, Switzerland.
4-9 October	Atlanta, Georgia, United States	Seventeenth American Water Resources Conference on "Wastes impact on water"; and International Symposium on Water Resources and Human Health, and Mini-symposium on Unified River Basin Management. Contact: American Water Resources Association, St. Anthony Falls Hydraulic Laboratory, Mississippi River at 3rd Avenue S.E., Minneapolis, Minnesota 55414, United States.
6-8 October	Burlington, Ontario, Canada	Time series methods in hydrosciences. Topics for discussion encompass stochastic model-building in the hydrosciences, transfer function models, forecasting and control techniques, intervention analysis, analysis of non-regular time series, analysis of spatial pattern, regression with correlated errors. For further information contact A. El-Shaarawi, N.W.R.I. Canada Centre for Inland Waters, P.O. Box 5050, Burlington L7R 4A6, Ontario, Canada.
4-9 October	Rabat, Morocco	IWSA Specialized Conference on Eutrophication and Water Supply will discuss the causes, consequences, prevention and control of eutrophication, and will include a visit to the Bou Regreg reservoir. Contact: Organisation Committee of the Specialised Conference, Rabat IWSA, c/o Setude, 27 Boulevard des Italiens, F-75002 Paris, France.
12-13 October	Sydney, Australia	Conference on Hydraulics in Civil Engineering is being organized by the Institution of Engineers, Australia, for interested engineers, scientists and technologists at the New South Wales Institute of Technology.
13-14 October	Kansas City, Missouri, United States	Sixth Symposium on Aquatic Toxicology will provide a forum for discussion of data, methods, research and results, and new concepts in both applied and theoretical aquatic toxicology and hazard assessment. For further information contact W.E. Bishop, The Procter & Gamble Company, Cincinnati, Ohio, or R.D. Cardwell, Envirosphere Co., Bellevue, Washington 98004, United States.
18-23 October	California, United States	Fourth Conference on Water Chlorination: Environmental Impact and Health Effects will be held at the California Asilomar Conference Grounds. The Conference will include discussion of chlorination, chemistry, chemical methods, helath effects, disinfection, biofouling control, aquatic ecosystem effects and risk assessment. For further information contact Dr. Robert L. Jolley, Oak Ridge National Laboratory, P.O. Box X, Oak Ridge, Tennessee 37830, United States.
22-23 October	Zurich, Switzerland	Symposium on Reservoir Sedimentation in the Alps. Details are available from the Schweizerische Wasserwirtschaftsverband, Rütistrasse 3A, CH-5401 Baden, Switzerland.
27 October - 3 November	Paris, France	Ecology in Practice -- Establishing a Scientific Basis for Land Management. Contact MAB UNESCO, 7 Place de Fontenoy, Paris, France.
1-5 November	Dubai, United Arab Emirates	Arab Water Technology Exhibition and Conference will be held at the Dubai International Trade Centre. The Conference is being organized by Middle East Water & Sewage, and will cover the complete water cycle from water source to sewage treatment.

23-27 November	Brussels, Belgium	"Aqua-Expo"-- the second exhibition will take place in the Brussels Exhibition Centre, organized by the Brussels International Trade Fair in co-operation with the Belgian National Association of Water Services. It will be devoted to the techniques, materials and accessories for collection, pumping, transport and treatment (mechanical, biological, chemical) of water and waste water, and the treatment of mud and water distribution. Simultaneously with this event, the Belgian Committee of the International Association on Water Pollution will hold a conference about "Micropollutants in the environment".
25-27 November	Perth, Australia	Fifth Australian Conference on Coastal Engineering. Topics for discussion include off-shore engineering, wave climates, tropical cyclones, foundation problems, forces on structures; coastal engineering, stabilization, coastal management, estuarine phenomena; and dune management and drift control. For further information contact the Conference Manager, The Institution of Engineers, Australia, 11 National Circuit, Barton, A.C.T. 2600, Australia.
5-10 December	Dacca, Bangladesh	National Symposium on River Basin Development is being organized by the Ministry of Power, Water Resources and Flood Control, in co-operation with UNDP. Topics for discussion include development of the basins of the Ganges, Brahmaputra and Meghna rivers and similar basins elsewhere, and international river law and conventions applicable to co-operative basin development.
11-13 December	Roorkee, India	International Symposium on Water Resources, Conservation, Pollution and Abatement. The themes of the Conference are water pollution and control; optimal utilization of water resources; transport of solids in channels; scour and sediment deposition and their effects. Contact: Dr. R.P. Mathur; Symposium on Water Resources, Conservation, Pollution and Abatement; Civil Engineering Department, Roorkee University, Roorkee U.P. 247 672, India.
1981/82	Loughborough, Leicestershire, England	"Water and waste engineering for developing countries" -- an M.Sc. course which caters exclusively for water and waste engineering in developing countries. Emphasis is on the priority areas for the Water Decade--rural water supply and low-cost sanitation. Maintenance, administration, finance and sociological factors as they apply in developing countries, as well as treatment processes, and the design and construction of engineering works, are important aspects of the course. Applications for the 1981/82 course should be made as soon as possible. Contact: Mr. J. Pickford, WEDC, Department of Civil Engineering, University of Technology, Loughborough, Leicestershire LE11 3TU, England.

1982

9-14 January	Lagos, Nigeria	Fourth ICID Afro-Asian Regional Conference on River Basin Development for Food Production includes the following topics for discussion: efficient water management in irrigation projects; problems of weeds, salinity, erosion and drainage in irrigation projects; and control of seepage in irrigation channels, particularly in field channels. For further details contact E.U. Nwa, Organizing Secretary, ICID 1982, c/o Federal Ministry of Water Resources, 9 Kofo Abayomi Rd., Victoria Island, P.M.B. 12613, Lagos, Nigeria.

15-17 February	London, England	"Plastics and rubber in water and effluents". A conference on this subject will be held at the Royal Lancaster Hotel, London, sponsored jointly by the Institute of Water Pollution Control, the Institution of Public Health Engineers, the Institution of Water Engineers and Scientists, the Plastics and Rubber Institute and the Water Research Centre. The aim is to bring together all those concerned with the production and use of plastics and rubber in water and effluents. For further information please contact the Plastics and Rubber Institute, 11 Hobart Place, London SW1W OHL, England.
Spring 1982	Denver, Colorado, United States	American Water Resources Association Symposium on Hydrometeorology. Contact: AWRA, St. Anthony Falls Hydraulic Laboratory, Mississippi River at 3rd Avenue S.E., Minneapolis, Minnesota 55414, Unites States.
18-24 March	New Delhi, India	Thirty-third ICID-IEC Meeting.
29 March - 2 April	Cape Town, South Africa	Eleventh Conference of the International Association on Water Pollution will focus on latest research results on water pollution and its control, and on technology transfer. Contact: Secretary/Treasurer, IAWPR, Chichester House, 278 High Holborn, London WC1, England.
6-10 April	Acapulco, Mexico	International Water Decade Conference and Exhibition. Contact: Frenwest Exhibitions Limited, County House, 10, Little Portland Street, London W1N 5 DF, England.
19-30 April	Exeter, England	First Scientific Assembly of International Association for Hydrological Sciences to be convened outside the General Assemblies of the International Union of Geodesy and Geophysics will be held at the University of Exeter, supported by UNESCO and WMO. The six Commissions will each organize one symposium, and the topics are: advances in hydrometry; optimal allocation of water resources; improvement of methods of long-term prediction of variations in ground-water resources and regimes due to human activities; recent development in the explanation and prediction of erosion; hydrological aspects of alpine and high mountain areas; water quality symposium. Further information can be obtained from the Secretary, John C. Rodda, Water Data Unit, Reading Bridge House, Reading, Berkshire RG1 8PS, England.
May	Rio de Janeiro, Brazil	Fourteenth Congress of ICOLD.
10-12 May	Marseille, France	Fourth International Conference on Planning and Management of Water Resources for Industrial, Agricultural and Urban Use is being organized by the Commission Européenne Méditerranéenne de Planification des Eaux, in collaboration with other organizations. For further information write to Secretariat de la Conference, Société des Eaux de Marseille, 25 rue Edouard Delanglade, 13006 Marseille, France.
11-13 May	Melbourne, Australia	1982 Conference on Hydrology and Water Resources is being sponsored by the National Committee on Hydrology and Water Resources of The Institution of Engineers, Australia and the Australian Forestry Council. The Conference combines the First National Symposium on Forest Hydrology with the Institution's annual Hydrology and Water Resources Symposium, and encourages interaction between workers in the engineering and forestry streams of hydrology and water resources in Australia.
15-18 June	Honolulu, Hawaii, United States	International Conference on Rainwater Cistern Systems. Contact: Water Resources Research Center, University of Hawaii, 2540 Dole Street, Holmes Hall 283, Honolulu, Hawaii 96822.

26-30 July	Hannover, Federal Republic of Germany	Fourth International Conference on Finite Elements in Water Resources.
31 August - 3 September	Canberra, Australia	Conference on Groundwater in Fractured Rock is being organized by The Australian Water Resources Council (AWRC) to bring together people concerned with the research, assessment and management of groundwater in fractured rock. Contact: The Secretary, AWRC Conference on Groundwater in Fractured Rock, c/o Bureau of Mineral Resources, Geology and Geophysics, P.O. Box 378, Canberra City, ACT 2601, Australia.
5-11 September	Warsaw, Poland	Third International Congress on Ecology. Contact: Prof. Dr. R. Klekowski, Institute of Ecology PAN, Dziekonow Cesny, 05-150 Lomianki, Poland.
21-23 September	Berne, Switzerland	International Symposium on Hydraulic Research Basins, and Their Use in Water Management. Contact: Dr M. Spreafico, International Symposium on Hydrological Research Basins, Service hydrologique nationale, case postale 2742, 3001 Berne, Switzerland.
Fall 1982		Eighteenth American Water Resources Conference and Symposium. Contact: AWRA, St. Anthony Falls Hydraulic Laboratory, Mississippi River at 3rd Avenue S.E., Minneapolis, Minnesota 55414, United States.
14-19 November	Cape Town, South Africa	Eighteenth International Conference on Coastal Engineering. Topics for discussion include wind, current and wave action, tides and long waves, sedimentary processes and coastal morphology, estuary and inlet behaviour, coastal structures and recreational facilities, ship motions as related to harbour entrance design, ocean outfall design and construction, environmental aspects in coastal engineering design. Contact: Symposium Secretariat, S. 204 CSIR, P.O. Box 395, Pretoria, 0001 Republic of South Africa.

Water Resourcefulness Department

"Survival-Evolution" ice sculpture

Through the Australian National Committee for the International Hydrological Programme of UNESCO, Australia sent a water sample especially taken from a mountain stream in Kosciusko National Park to be included in a frozen water sculpture commemorating United Nations Day, 24 October 1981. The entire sculpture, 12 ft high and 80 ft long was composed of letters of ice that spelled out the world 'SURVIVAL' and contained sample waters collected from each of the United Nations. It was scheduled for display at the San Francisco Museum of Modern Art.

This unique art project was endorsed by UNESCO and was the first project of a new non-profit corporation dedicated to the integration of art and the environment. In its transformation from solid to liquid, the sculpture was intended to be in itself a demonstration of an evolutionary process. In the words of the California artist, Joyce Cutler Shaw, "... as the sculpture melts, the water will be conserved for reuse for practical purposes, an extension of its symbolic and artistic life as a centre piece of the Survival-Evolution project".

From *Water Resources Newsletter* (Australia), 1981

Selected Abstracts

Abstracts of current literature on water resources topics are reprinted in the following pages. Selection of the abstracts presented in each issue of *Water Resources Journal* is based on relevance to conditions prevailing in Asia and the Pacific, and to the objectives of water resources development programmes in the region.

The selected abstracts in this issue of the *Journal* are organized under the following topics.

Conservation in agriculture
Control of water on the surface
Data network design
Evaluation process
Erosion and sedimentation
Ground water
Hydraulic structures
Hydraulics
Planning techniques
Pollution identification
Pollution sources
Precipitation
Streamflow and runoff
Ultimate disposal of wastes
Use of water of impaired quality
Water demand
Water in soils
Watersheds

CONSERVATION IN AGRICULTURE

"A conceptual framework for evaluating agricultural water conservation potentials", by David C. Davenport and Robert M. Hagan.

Paper Number 79131 of the *Water Resources Bulletin*, American Water Resources Association, ISSN 0043-1370, vol. 16, No. 4, August 1980, pp. 717-723.

This paper defines types of water losses in irrigated agriculture and outlines potentials for water conservation. Recoverable water "losses" (seepage, leakage, and spillage during storage and conveyance, and surface runoff and deep percolation during irrigation) and irrecoverable losses (evaporation from water and soil surfaces and transpiration from plants) are described and illustrated. Some conservation terms are defined, particularly the distinction between on-farm irrigation efficiency and areawide efficiency. Briefly reviewed are agricultural water conservation technologies and their applicability. The biggest untapped potential for water conservation may be a reduction in irrecoverable losses, especially evapotranspiration. The advantages and disadvantages of reducing recoverable and irrecoverable water losses are described, including possible effects on ground water, energy, salinity, crops, wildlife, and in-stream uses. Such information may be useful in several policy and management issues, e.g., ground water overdraft and possible constraints on crops and sites to be irrigated.

(KEY TERMS: agricultural water conservation; evaporation; evapotranspiration; ground water; irrigation efficiency; transpiration reduction; water reuse; water quality; wildlife.)

CONTROL OF WATER ON THE SURFACE

"Derivation of monthly reservoir release policies", by Nageshwar R. Bhaskar and Elbert E. Whitlatch, Jr.

Paper number 80W1005, *Water Resources Research*, American Geophysical Union, ISSN 0043-1397, vol. 16, No. 6, December 1980, pp. 987-993.

A single multiple-purpose reservoir is analyzed using a backward looking dynamic program algorithm to obtain optimal releases. The dynamic program is solved for both one-sided and two-sided quadratic loss functions. Monthly policies are derived by regressing the optimal set of releases on the input and state variables. Linear and nonlinear release policies are developed, then verified and compared through simulation. For a two-sided quadratic loss function, linear policies are as good or better than nonlinear policies. However, for a one-sided quadratic loss function, nonlinear policies give improved performance over linear policies. It is also illustrated that the maximum R^2 criterion for selecting release policies may not always be appropriate. Hoover Reservoir, located on Big Walnut Creek in central Ohio, is used as a case example.

DATA NETWORK DESIGN

"Water data and services available from participants in the national water data exchange", by Melvin D. Edwards.

Paper number 79112 of the *Water Resources Bulletin*, American Water Resources Association, ISSN 0043-1370, vol. 16, No. 1, February 1980, pp. 1-14.

The National Water Data Exchange (NAWDEX) was implemented in January 1976 as an interagency program managed and coordinated by the U.S. Geological Survey. The program is directed at improving access to existing water and water-related data. Almost 150 organizations from the Federal, state-governmental, local-governmental, interstate, academic, private, and foreign sectors currently participate in the program. This article describes the NAWDEX program and contains descriptions of the types of data and services available from organizations participating in NAWDEX. A point of contact for obtaining data and services is provided for each organization.

(KEY TERMS: data exchange; data services; data systems, environmental data; hydrologic data; National Water Data Exchange; NAWDEX; water data; water-related data.).

EVALUATION PROCESS

"A comparison of methods and instrumentation of biological early warning systems", by John Cairns, Jr. and David Gruber.

Paper number 79123 of the *Water Resources Bulletin*, American Water Resources Association, ISSN 0043-1370, vol. 16, No. 2, April 1980, pp. 261-266.

Rapid biological information systems using aquatic organisms to monitor water and waste water quality have only recently begun to develop technologically for practical on-site applications. One approach which has been demonstrating its feasibility recently monitors the ventilatory behavior of fish to assess, for example, the quality of drinking water supplies and industrial waste water discharges. A comparison of the basic strategies of the various biological monitoring systems making use of this concept is presented. In addition, the applications and potential utilization of these systems are discussed.

(KEY TERMS: biological monitoring; effluent monitoring; fish ventilation; monitoring; pollutant monitoring; waste water discharges.).

"Effect of urbanization on alternative flood control strategies", by Richard C. Bost, Philip B. Bedient and Peter G. Rowe.

Paper number 79127 of the *Water Resources Bulletin*, American Water Resources Association, ISSN 0043-1370, vol. 16, No. 4, August 1980, pp. 710-716.

The effect of urbanization on alternative flood control strategies was investigated for a large developing watershed in Texas. Urban and rural areas were modeled separately using a geographically referenced data base and the U.S. Corps of Engineers HEC-1 and HEC-2 programs, and results yielded a double-peaked hydrograph. Hydrograph input parameters were modified to predict the effects of a wide range of management alternatives including on-site storage, reservoirs, channelization, and development controls. Results indicated a combination of alternatives is required to protect existing and future developments.

(KEY TERMS: floodplain management; hydrologic modeling; flood control; land use; urban hydrology.)

"Institutional analysis criteria for water supply planning", by Gary R. Minton, Richard Williams and Thomas Murdock.

Paper number 79049 of the *Water Resources Bulletin*, American Water Resources Association, ISSN 0043-1370, vol. 16, No. 3, June 1980, pp. 486-493.

This paper discusses the selection and use of criteria for an institutional analysis of municipal water supply conducted in Anchorage, Alaska. Although not universally accepted or used, evaluation criteria for most technical fields have been established either formally or informally. Cost-benefit ratios, cost-effectiveness, and environmental impacts are examples of technical evaluation criteria that can be quantified relatively easily (although poorly in some cases). The field of institutional analysis has evaluative criteria that are much less readily defined than those of technical fields, in part because many of the criteria are not quantifiable and in part because the area of the study is new.

(KEY TERMS: institutional analysis; water supply; planning; Anchorage, Alaska; Alaska.)

"Modeling a sociological-hydrologic flood control decision system", by Wade H. Andrews, J. Paul Riley and Malcolm B. Masteller.

Paper number 78092 of the *Water Resources Bulletin*, American Water Resources Association, ISSN 0043-1370, vol. 16, No. 2, April 1980, pp. 194-202.

This work was the development of a model for analyzing the social components of a flood control or sociological-hydrologic decision process. A general conceptual system was developed from the study of an actual decision. Mathematical values were determined for the social and behavioral variables and these elements were transposed into a mathematical linear model providing a set of equations from which the system could be simulated with the computer.

(KEY TERMS: social; sociological-hydrologic; flood control; decision model; decision system; model; simulation.)

"Spatial and temporal aggregation effects in a regional water supply planning model", by Paul H. Kirshen.

Paper number 9W1750, *Water Resources Research*, American Geophysical Union, ISSN 0043-1397, vol. 16, No. 3, June 1980, pp. 457-464.

In applying mathematical programing water supply planning models, water supplies and demands must be spatially and temporally aggregated. An assessment is made of the effects of aggregation on the results of a planning model for West Africa. The assessment uses a detailed hydroeconomic simulation model to study the solution set of the planning model when it has been applied to several representative subareas. Comparisons are made between the design reliability intended for the supply system and the actual reliabilities of sources as estimated by the detailed simulation model. Comparisons are also made between the system suggested by the planning model and the estimated least cost reliable system. (The least cost reliable system was found using a trial and error search method and the detailed simulation model.) It was found that the aggregation assumptions primarily affect the modeling of sources that depend directly on the highly variable precipitation (e.g., ephemeral aquifers). These sources should, in general, be excluded from the planning model and analyzed separately. Overall, unless a planner is particularly interested in studying the use of such unreliable sources, the spatial and temporal aggregation assumptions of the planning model do not hinder its use as an effective regional planning tool.

EROSION AND SEDIMENTATION

"Reservoir sedimentation with random deposits", by Huynh Ngoc Phien, Anat Arbhabhirama and Pinit Chenyapanich.

Paper number 79093 of the *Water Resources Bulletin*, American Water Resources Association, ISSN 0043-1370, vol. 16, No. 5, October 1980, pp. 818-823.

The accumulated volume of sediment in reservoirs is investigated in this paper using a statistical method. Based on the fact that sediment load and river discharge are highly correlated, a relationship between them is established. With longer records of stream flows, this relationship will serve either as a data generation mechanism which produces a sediment S-sequence having the same length as the river discharge Q-sequence, or as a transformation of variables, by which the distribution of S is transferred from the distribution of Q. The mean and variance of the sediment volume accumulated in the design life of a reservoir are then derived, assuming the S- and Q-sequences follow the log-normal distribution. Finally, case studies are given for illustrating the proposed method.

(KEY TERMS: reservoir sedimentation; sediment pool; trap efficiency; log-normal distribution; Markov model.)

GROUND WATER

"A ground-water resources study of a Pacific Ocean atoll - Tarawa, Gilbert Islands", by J.W. Lloyd, J.C. Miles, G.R. Chessman and S.F. Bugg.

Paper number 80007 of the *Water Resources Bulletin*, American Water Resources Association, ISSN 0043-1370, vol. 16, No. 4, August 1980, pp. 646-653.

The geology and fresh ground water lens development in a typical Pacific atoll are described together with a method for hydrogeological investigation. The fresh water resources of such lenses are investigated using Tarawa as an example. It is shown that simple steady state solutions cannot be realistically applied, and that despite the paucity of hydrogeological data, which is considered typical of such islands, practical nonsteady state solutions allow resource assessments. The susceptability of lens resources to drought conditions is demonstrated.

(KEY TERMS: ground water resources; atolls, Gilbert Islands; hydrology.)

"The use of Landsat imagery in ground-water exploration" by Kennith E. Foster, Robert A. Schowengerdt and Charles E. Glass.

Paper number 80031 of the *Water Resources Bulletin*, American Water Resources Association, ISSN 0043-1370, vol. 16, No. 5, October 1980, pp. 934-937.

Water supplies in Arizona are becoming increasingly limited because municipal, industrial, and agricultural consumption depletes ground water reserves by three million acre-feet annually.

Additional demands are being created by electric power generation, particularly in northeastern Arizona where ground water pumpage is expected to escalate by sixfold during the next 10 years. The results of a study to determine the ease and feasibility of using satellite imagery as a tool in exploring for new sources of ground water are reported. Lineaments detected on Landsat images of two sites were mapped and correlated with well data in the two study areas by means of well centered grid model. The correlations developed between lineament density and water well data in the two study sites support the hypothesis that a relationship exists between regional geologic structure and the presence of ground water.

(KEY TERMS: remote sensing; ground water exploration.)

HYDRAULIC STRUCTURES

"A decision theory approach to earth dam classification", by Richard H. McCuen.

Paper number 79122 of the *Water Resources Bulletin*, American Water Resources Association, ISSN 0043-1370, vol. 16, No. 3, June 1980, pp. 546-549.

The fact that dams have failed indicates that there is still a risk involved, in spite of the major effort to ensure reliability. In seeking ways to reduce the risk, all aspects of the design, construction, monitoring, inspection, and rehabilitation of earth dams should be examined. Because dam classification is a central element, ways of minimizing uncertainty associated with classification need to be considered. A Bayesian approach to classification has numerous advantages over existing methods of earth dam classification because it directly evaluates the effects of uncertainties. A framework for incorporating Bayesian decision theory into the classification process is presented.

(KEY TERMS: dams; decision theory; earth dams; failure; inspection; safety; statistical analysis.)

"Optimum design of irrigation pipelines", by Dr. Helmi Mohammad Hathoot.

ICID Bulletin, International Commission on Irrigation and Drainage, vol. 29, No. 2, July 1980, pp. 73-75.

The writer presents in this paper a study on the optimum design of a pipeline provided with similar equidistant pump stations.

In this study the writer introduces the effect of the type of flow, hydraulically smooth or hydraulically rough, on the design and two new design formulae are established.

The above design formulae include coefficients representing the actual cost of pipes as well as that of pumping units, each per metre run of the pipeline.

"Recreational enhancement of high-country, water-supply reservoirs", by John W. Labadie, John M. Shafer and Robert Aukerman.

Paper number 79080 of the *Water Resources Bulletin*, American Water Resources Association, ISSN 0043-1370, vol. 16, No. 3, June 1980, pp. 477-485.

There is considerable misconception about the dangers of opening water supply reservoirs to recreation use. Under proper management, many beautifully situated, single-purpose reservoirs could be opened to a recreating public in great need of additional open areas. A systematic procedure for identifying the factors essential to the selection, planning, and management of reservoirs for recreation is described. A detailed case study conducted by an interdisciplinary project team is presented to demonstrate the feasibility of maintaining storage levels in recreation-conducive high country reservoirs without unduly injuring downstream water users. The idea is to trade water with reservoirs having less recreation potential. The optimal means of doing this is found via a river basin simulation model with quasi-optimizing capability. Results of the case study show that this strategy is indeed feasible. Application to other areas may require analysis of tradeoffs if at least some damage [illegible] downstream users is unavoidable.

(KEY TERMS: recreation; reservoir operation; river basin simulation; optimization; Colorado.)

HYDRAULICS

"Biofilm growth and hydraulic performance", by Basil F. Picologlou, Nicholas Zelver and William G. Characklis.

Paper number 15421, *Journal of the Hydraulics Division*, American Society of Civil Engineers, ISSN 0044-796X, vol. 106, No. HY5, May 1980, pp. 733-746.

An experimental investigation of the deleterious effect of microbial slime layers on the hydraulic performance of water conduits is presented. The underlying mechanisms that lead to an increase of frictional losses in the conduit are explored and their relative importance is discussed. It is shown that although the slime layer is viscoelastic and filamentous, its effect on frictional resistance can be adequately represented through an increase in rigid equivalent sand roughness of the conduit wall.

(KEY WORDS: Biological properties; Energy losses; Films; Fouling; Friction resistance; Hydraulic pressure; Microbes; Pipelines; Roughness, Slime; Walls; Water supply.)

PLANNING TECHNIQUES

"Floodplain delineation: an economic approach", by William C. Hughes.

Paper number 79064 of the *Water Resources Bulletin*, American Water Resources Association, ISSN 0043-1370, vol. 16, No. 2, April 1980, pp. 267-270.

Errors inherent in the computation of water surface profiles are magnified by the shallow lateral slopes typical of most floodplains, producing significant floodplain mapping errors. An economic optimization procedure which weighs the cost of overstating the location of a floodplain boundary against the cost of understanding the location provides a means for establishing the boundary location. In most cases the cost of overstating the boundary location exceeds the cost of understating the location by several magnitudes so that the boundary location should coincide with the minimum water surface elevation which would be expected to result from a flood of specified recurrence interval.

(KEY TERMS. economic analysis; floodplain; mapping.)

"Many resources, many uses: a system analysis approach to renewable resource development", by Peter G. Ashton, James B. Pickens, Coryell Ohlander and Bruce Benninghoff.

Paper number 79058 of the *Water Resources Bulletin*, American Water Resources Association, ISSN 0043-1370, vol. 16, No. 4, August 1980, pp. 738-744.

Decisionmaking associated with the Nation's 1.7 billion acres of forest and range land has become increasingly complicated because of the rise in competition for resource use and in the awareness of environmental and social effects. This system analysis approach uses four models to synthesize pertinent masses of information into measures of economic, environmental, and social impacts. The system results can be used to help evaluate alternative national programs. The models are:

- The National Interregional Multiresource Use Model uses linear programming to allocate national and regional demands for renewable resource uses on the land base. This model minimizes operational costs of alternative programs while achieving environmental restraints, range production, sustained wood yield, and wilderness.

- The second model evaluates regional employment and earnings triggered by a national program.

- The third model, Futures Foregone, keeps count of future options lost in terms of the amount affecting citizens groups, rate of impact, and length of impact.

- The last model, Social Conflict, operates on the postulate that there will be proponents and opponents for any resource use and that some degree of conflict is inevitable. The model uses impact information including that generated from previous models and serves to quantify the amount and pattern of conflict.

The system serves to unify the four models in the context of evaluating cost effective alternatives against criteria of demands, environmental restraints, employment and income maintenance, minimizing loss of future options, and minimizing conflict patterns that damage community stability.

(KEY TERMS: multiresource use interaction; resource planning; linear programming; systems analysis; social well being; regional economic impacts.)

"Reclamation policy in water development areas", by G.E. Papadopoulos.

ICID Bulletin, International Commission on Irrigation and Drainage, vo. 29, No. 2, July 1980. pp. 13-17.

Any reclamation policy in water development areas refers primarily to the ways and methods for the optimal utilization of the projects irrigation potential. In its full (integral) aspects, the reclamation policy includes also, in addition to the building and the operation of irrigation projects, the field of the over-all territorial development, affected essentially by intensive farming and the deriving socio-economic beneficial results.

The paper analyses different aspects of certain basic concepts, such as "reclamation projects", "project development" and "project efficiency", which have to be considered and adopted by any reclamation policy.

The paper moreover refers to the project systems approach and to the ways of its application into the fields of project management, financing and beneficiaries.

In conclusion, the author points out the importance of a clear definition and formulation of the short and long-range scopes and objectives of the reclamation policy and of its methods and measures which must be strictly adjusted to its basic governing principles and conceptual approaches.

"Storm water management: the concept and its application", by Thomas N. Debo.

Paper number 79111 of the *Water Resources Bulletin*, American Water Resources Association, ISSN 0043-1370, vol. 16, No. 4, August 1980, pp. 654-660.

Storm water management is a concept being applied in many urban areas to deal with the increasing problems of storm runoff control and flood damage prevention. This paper introduces the concept and describes the recently completed storm water management program in Columbus, Georgia. Columbus has spent five years and over $200,000 in the development of their problem which includes several basic elements: soils inventory and analysis, hydrologic data collection, sediment and erosion control ordinance, storm water management handbook, urban flood simulation model, interdepartment coordination study, drainage problem categorization study, and a pilot basin study. The results of the pilot basin study are presented including example output from the urban simulation model. The computer output illustrates both the hydrologic-hydraulic and economic capabilities of the model.

(KEY TERMS: flood economic modeling; flooding; hydrologic-hydraulic modeling; planning; public works; storm water management; urban drainage.)

POLLUTION IDENTIFICATION

"Ridge regression techniques applied to Landsat investigation of water quality in Lake Okeechobee", by S.F. Shih and J.C. Gervin.

Paper number 79079 of the *Water Resources Bulletin*, American Water Resources Association, ISSN 0043-1370, vol. 16, No. 5, October 1980, pp. 790-796.

Landsat radiance values were processed at two different (single and double) levels of accuracy to estimate chlorophyll *a*, turbidity, and suspended sediment in Lake Okeechobee, Florida. Both ordinary least square and ridge regression analyses were used to establish a relationship between water quality parameters and Landsat radiance. Radiance measurements made at greater precision (double level) gave a better solution in this application. The ridge regression analysis for double level not only can reduce the total mean square error about 13-20 per cent and confidence interval about 6-28 per cent as compared to ordinary least square analysis, but it can also change the interpretation of analysis results.

(KEY TERMS: Landsat; GE image 100; chlorophyll *a*; turbidity; suspended sediment; water quality; Lake Okeechobee; ridge regression.)

POLLUTION SOURCES

"Ground-water pollution by transfer of oil hydrocarbons", by J.J. Fried, P. Muntzer and L. Zilliox.

Ground Water, Ground-water Technology Division, National Water Well Association, ISSN 0017-467X, vol. 17, No. 6, November-December 1979, pp. 586-594.

An important aspect of the pollution of a phreatic aquifer by hydrocarbons is the oil-water contact and transfer of soluble substances from the oil into the ground water.

A systematic study of this transfer of matter in a saturated porous medium (initial condition of contact when the impregnation body is submitted to fluctuations of the piezometric level) is performed with an experimental device made up of a porous matrix containing the oil phase, steady and crossed by a unidirectional flow of water. The transfer is very efficient; for all compounds which have been studied, the maximum possible concentration is reached after a distance of the order of 10 cm with specific flow rates greater than those generally encountered in a gravel-sand aquifer. The selective impoverishment of the oil product with time, due to differences in the solubility of various hydrocarbons, modifies the dissolved phase composition. Downstream of an in-situ impregnation body, this phenomenon only appears after a constant concentration has been reached for a long time. A source model is thus obtained, where the pollutant massic flow rate is proportional to the flow rate of the water which crosses the impregnation body. Such an initial condition has a fundamental effect on the determination of the contaminated aquifer domain, with the help of the dispersion scheme, with hydrocarbon concentrations evolving according to a general diffusion-convection law.

PRECIPITATION

"Gage density and location for estimating mean annual precipitation in mountainous areas", by Myron Molnau, Walter J. Rawls, David L. Curtis and C.C. Warnick.

Paper number 79050 of the *Water Resources Bulletin*, American Water Resources Association, ISSN 0043-1370, vol. 16, No. 3, June 1980, pp. 428-432.

Data from a network of 45 shielded precipitation gages on the Reynolds Creek Experimental Watershed in Southwestern Idaho were analyzed to determine the optimum gage density for estimating mean annual precipitation. Four subsets of the 45 gage network were used to derive a curve of mean annual precipitation versus number of gages with a confidence band at the 95 per cent level. When less than 20 gages were used in the estimate, the confidence interval widens rapidly. Estimates were improved by stratifying gages on the basis of plant cover class or by elevation bands. Sixty-four per cent of the variation in mean annual precipitation was accounted for by elevation and cover class. The aspect and hydrologic soil classification were not statistically significant.

(KEY TERMS: precipitation; gage location; gage density; mountainous area; annual precipitation.)

"Radar measurement of rainfall--a summary", by James W. Wilson and Edward A. Brandes.

Bulletin of the American Meteorological Society, ISSN 0003-0007, vol. 60, No. 9, September 1979, pp. 1048-1058.

Radar can produce detailed precipitation information for large areas from a single location in real time. Although radar has been used experimentally for nearly 30 years to measure rainfall, operational implementation has been slow. Today we find that data are underutilized and both confusion and misunderstanding exist about the inherent ability of radar to measure rainfall, about factors that contribute to errors, and about the importance of careful calibration and signal processing.

Areal and point rainfall estimates are often in error by a factor of two or more. Error sources reside in measurement of radar reflectivity factor, evaporation and advection of precipitation before reaching the ground, and variations in the drop-size distribution and vertical air motions. Nevertheless, radar can be of lifesaving usefulness by alerting forecasters to the potential for flash flooding.

The most successful technique for improving the radar rainfall estimates has been to "calibrate" the radar with rain gages. Simple techniques that combine sparse gage reports (one gage per 1000-2000 km^2) with radar produce smaller measurement errors (10-30%) than either system alone. When high accuracy rainfall measurements are needed (average error less than about 10-20%) the advantage of radar is diminished, since the number of gages required for calibration is itself sufficient to provide the desired accuracy.

STREAMFLOW AND RUNOFF

"A logical approach to the design storm concept", by J.C. Packman and C.H.R. Kidd.

Paper number 80W0997, *Water Resources Research*, American Geophysical Union, ISSN 0043-1397, vol. 16, No. 6, December 1980, pp. 994-1000.

Flood estimation using isolated event simulation models requires selection of a suitable combination of design storm and antecedent conditions. Current practice in storm drainage design is to adopt arbitrarily a storm duration, profile, and catchment wetness and to assume that the return periods of rainfall depth and flood peak are equal. This paper describes how sensitivity analysis may be used to examine the relationship between rainfall and flood return periods and, thereby, to determine systematically a suitable set of design inputs which give a peak runoff of the required return period. This process permits this particular model to be used with confidence in design as well as in simulation.

"Analysis of detention basin systems", by Russell G. Mein.

Paper number 80050 of the *Water Resources Bulletin*, American Water Resources Association, ISSN 0043-1370, vol. 16, No. 5, October 1980, pp. 824-829.

A runoff routing model, originally developed for rural areas and later adapted for application in urban areas, is shown to be very suitable for use in design detention basin systems. The model computes design inflow hydrographs for basins and routes flow through basins to the next downstream point of interest. Some general conclusions are drawn on the effects of different basin configurations.

(KEY TERMS: detention basins; runoff routing; design hydrograph; mathematical model.)

"Characteristics of low flows", by Henry C. Riggs.

Paper number 15400, *Journal of the Hydraulics Division*, American Society of Civil Engineers, ISSN 0044-796X, vol. 106, No. HY5, May 1980, pp. 717-731.

A Task Committee (TC) of the Surface Water Hydrology Committee was organized in 1976 to determine the types of low-flow information needed, to describe available methods of characterizing low flows, and to identify needed analyses and data collection. Responses to a TC survey of users of low-flow information indicated the need for better estimates of low-flow characteristics at ungaged sites. Available analytical methods are described and evaluated, sources of low-flow information are given, and some recently proposed techniques are reported. Low-flow data on many additional streams are needed.

KEY WORDS: Droughts; Forecasting; Hydrology; Low flow; Stream flow; Water resources

ULTIMATE DISPOSAL OF WASTES

"Chemical changes in an industrial waste liquid during post-injection movement in a limestone aquifer, Pensacola, Florida", by G.G. Ehrlich, E.M. Godsy, C.A. Pascale and John Vecchioli.

Ground Water, vol. 17, No. 6, November-December 1979, pp. 562-573.

The U.S. Geological Survey initiated a nation-wide research program in 1970 to study the effects of subsurface liquid waste injection on the environment. The main purpose of the program is to obtain hydrologic, geologic, geochemical, and biochemical data needed to develop techniques to predict the ultimate impact of waste injection on the subsurface environment.

An industrial waste liquid containing organonitrile compounds and nitrate ion has been injected into the lower limestone of the Floridan aquifer near Pensacola, Florida since June 1975. Chemical analyses of water from monitor wells and backflow from the injection well indicate that organic carbon compounds are converted to CO_2 and nitrate is coverted to N_2. These transformations are caused by bacteria immediately after injection, and are virtually completed within 100 m of the injection well. The zone near the injection well behaves like an anaerobic filter with nitrate respiring bacteria dominating the microbial flora in this zone.

Sodium thiocyanate contained in the waste is unaltered during passage through the injection zone and is used to detect the degree of mixing of injected waste liquid with native water at a monitor well 312 m (712 ft) from the injection well. The dispersivity of the injection zone was caluculated to be 10 m (33 ft). Analyses of samples from the monitor well indicate 80 per cent reduction in chemical oxygen demand and virtually complete loss of organonitriles and nitrate from the waste liquid during passage from the injection well to the monitor well. Bacterial densities were much lower at the monitor well than in backflow from the injection well.

"Waste water disposal through a coastal aquifer", by Irfan A. Khan.

Paper number 79081 of the *Water Resources Bulletin*, American Water Resources Association, ISSN 0043-1370, vol. 16, No. 4, August 1980, pp. 608-614.

Feasibility of disposing treated sewage in wells sunk into a partially confined coastal limestone aquifer at Waimanalo in the island of Oahu was investigated using an electric analog model. Electric analog modeling was preferred over digital modeling because of ease with which tides could be generated at the ocean boundary in the form of sinusoidal waves. The results of model operation showed that high permeability, low storativity, and the presence of ocean render the Waimanalo aquifer highly suitable for the disposal of waste water in deep wells. Since the quality of water in the aquifer is already unsuitable for municipal, industrial, or agricultural use, waste water injection will not result in any loss of fresh water supply source to the island. It is also believed that the cost of waste water disposal through the aquifer will be considerably less than that through an ocean outfall. During model development it was discovered that electric analog models can help prepare certain graphs which can be useful for aquifer analysis without any further use of the model.

(KEY TERMS: waste water disposal; coastal aquifer; electric analog model.)

USE OF WATER OF IMPAIRED QUALITY

"A model for optimal irrigation scheduling with saline water", by D. Yaron, E. Bresler, H. Bielorai and B. Harpinist.

Paper number 9W1564, *Water Resources Research*, American Geophysical Union, ISSN 0043-1397, vol. 16, No. 2, April 1980, pp. 257-262.

The paper presents a dynamic programing model for optimal scheduling of irrigation with water of varying salinity levels and soil salinity parameters explicitly considered. The system underlying the model is characterized by two discrete state variables, soil moisture and the salinity level of the soil solution, which are updated on a day-by-day basis. Transformation functions from one state to another in response to irrigation decisions and a crop response function to soil moisture and salinity are the other elements of the model, with the objective being maximization of income derived from the irrigated crop. An application to the irrigation of sorghum in the southern semiarid area of Israel is presented and evaluated.

WATER DEMAND

"A method for estimating peak water demand of multifamily residences", by B. Bobee, P. Boucher and H. Demard.

Paper number 79118 of the *Water Resources Bulletin*, American Water Resources Association, ISSN 0043-1370, vol. 16, No. 4, August 1980, pp. 729-738.

The importance of estimating peak water demands for determining the dimensions of pipe size and meters which provide household water to multifamily residences is examined. Several methods utilized in North America and Europe are examined. The analysis makes clear the necessity of studying the peak water demand through statistics based on local data concerning multifamily residences. For different periods of return, the peak demand of a given apartment building is related to its size (the number of apartments) in order to compare the results obtained with existing formula.

By use of Ridge-regression technique, the relationship between peak water demand, and building size (number of apartments) and available pressure is established. It can be concluded that peak demand can be estimated with the square root of number of apartment units in the building and the cube root of water pressure.

(KEY TERMS: water demand; residences; peak demand; meters; statistical distribution; Pearson type 3; log-Pearson type 3; Ridge-regression.)

"Estimating Irrigation Water Quantity and Quality", by Otto J. Helweg and Desi Alvarez.

Paper number 15712, *Journal of the Irrigation and Drainage Division*, American Society of Civil Engineers, ISSN 0044-7978, vol. 106, No. IR3, September 1980, pp. 175-188.

The value of water quantity and quality is shown by its demand curve (surface). But because the market for water is imperfect, the demand surface must be derived by other means. This paper shows a theoretical process for determining the derived demand surface for both water quantity and quality, using data for citrus crops in California. The results show that for the relevant price range, the demand for water quantity is relatively inelastic, indicating that pricing is not an attractive mechanism for controlling water distribution, however, the demand for water quality is relatively elastic which makes pricing a possible means for managing water quality. The results also support the claim that the value of water is considerably more than most irrigators pay for it.

KEY WORDS: Demand; Demand (irrigation systems); Irrigation water; Value analysis; Water allocation (policy); Water management (applied); Water pricing; Water quality

WATER IN SOILS

"Survey of methods for soil moisture determination", by T.J. Schmugge, T.J. Jackson and H.L. McKim.

Paper number 80W0815 of *Water Resources Research*, American Geophysical Union, vol. 16, No. 6, December 1980, pp. 961-979.

Increased interest in soil moisture information for applications in such disciplines as hydrology, meteorology, and agriculture has necessitated an overview of both existing and proposed methods for determination of soil moisture. This paper thus discusses methods of in situ soil moisture determination including gravimetric, nuclear, and electromagnetic techniques; soil physics models that track the behavior of water in the soil in response to meteorological inputs (precipitation) and demands (evapotranspiration); and remote sensing approaches that use the solar, thermal infrared, and microwave portions of the electromagnetic spectrum. The abilities of these approaches to satisfy various user needs for soil moisture information vary from application to application. Therefore we have proposed a conceptual scheme for merging these approaches into an integrated system. This system should provide soil moisture information having the potential for meeting the requirements of various applications.

WATERSHEDS

"Watersheds as the basic ecosystem: this conceptual framework provides a basis for a natural classification system", by Frederick B. Lotspeich.

Paper number 79095 of the *Water Resources Bulletin*, American Water Resources Association, ISSN 0043-1370, vol. 16, No. 4, August 1980, pp. 581-586.

A scheme is outlined to classify watersheds as ecosystems, based on their natural attributes. Two physical factors of the environment, climate and geology, are selected as state factors. Climate is the master factor that supplies energy and water to all ecosystems; geologic structure supplies the material from which the forces of climate carve landforms to establish ecosystems. At the next lower level, soil and vegetation interact in a succession of transactions to produce a mosaic of tesseras within each watershed. It is these interacting tesseras that moderate climate and store energy within the ecosystem that influences the embedded stream. At the bottom of the scale is the stream with its passive role and inability to interact with the higher factors of the ecosystem. Thus, we have a controlling force consisting of two elements (climate and geology), a reacting force (soil and vegetation) that responds by circular conditioning to controlling forces, and at the lowest level, the stream which responds to all factors of the living system within its watershed.

(KEY TERMS: watersheds; ecosystem; classification; physioclimatic control; transactional factors.)

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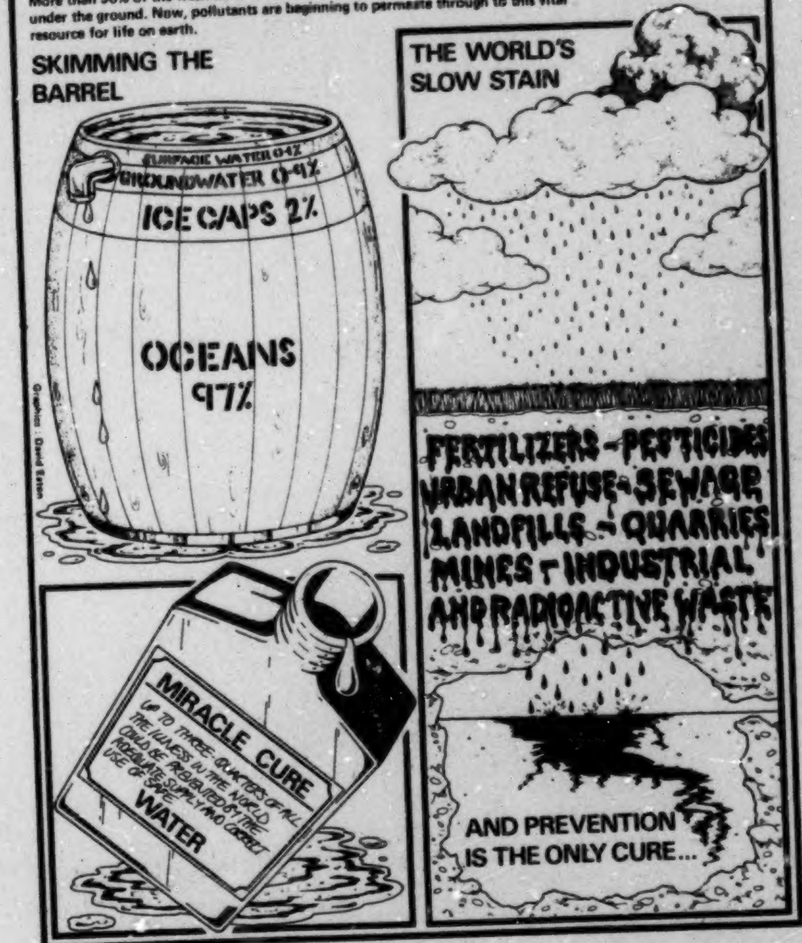
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GROUNDWATER 0·9%
ICE CAPS 2%
OCEANS 97%
THE WORLD'S SLOW STAIN
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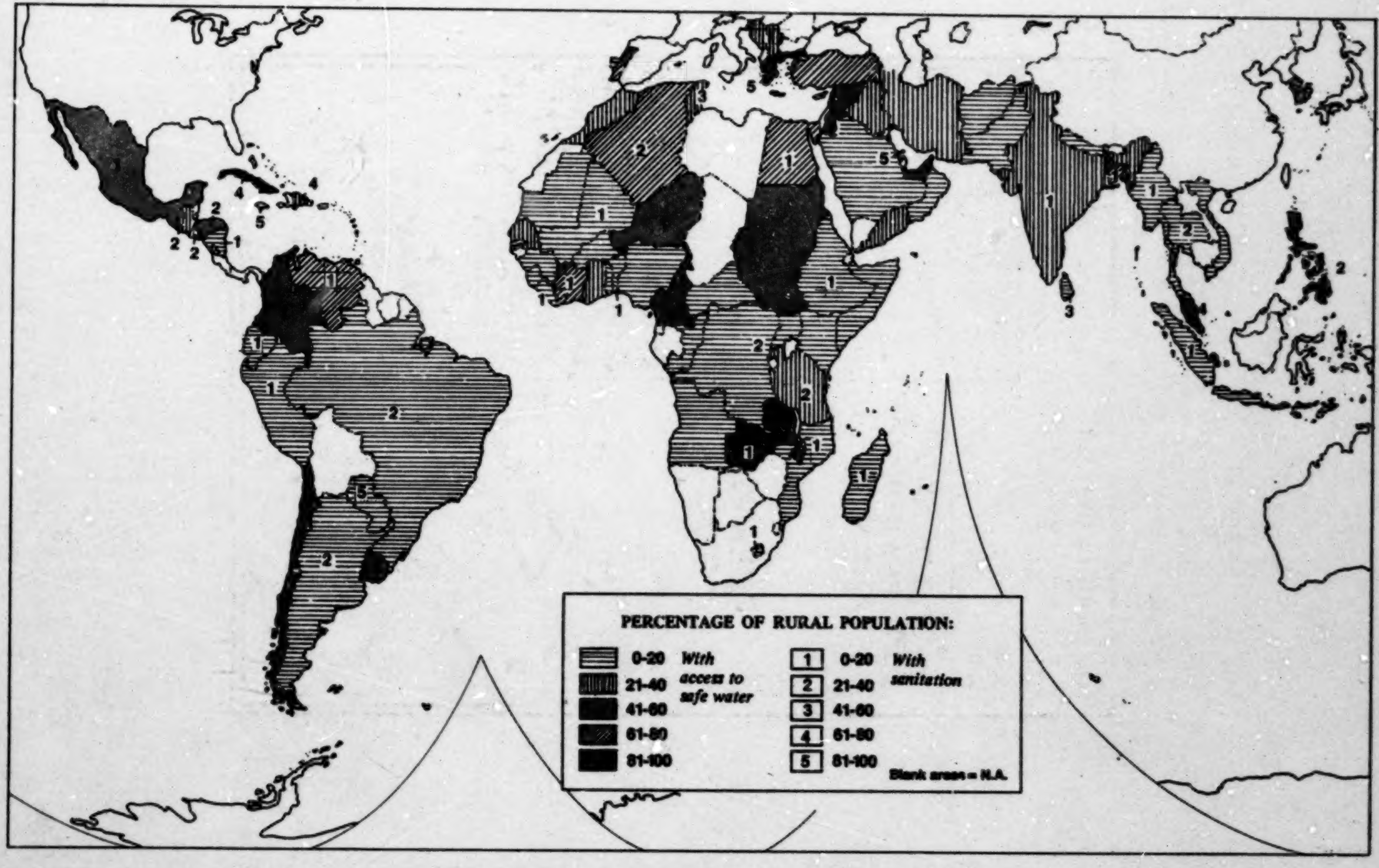
WITH
ACCESS TO SAFE WATER AND SANITATION

(excluding the South Pacific area)


PERCENTAGE OF RURAL POPULATION:
▤ 0-20
▥ 21-40
■ 41-60
▨ 61-80
■ 81-100
With access to safe water
1 0-20
2 21-40
3 41-60
4 61-80
5 81-100
With sanitation
Blank areas = N.A.